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THE UNIVERSITY OF ALBERTA

AN ATTEMPT TO ISOLATE SOIL FACTORS CONTRIBUTING TO CROP RESPONSE ON A DEEP PLOWED DUAGH SOLONETZ

by

© D. Brook Harker

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "An Attempt to Isolate Soil Factors Contributing to Crop Response on a Deep Plowed Duagh Solonetz" submitted by D. Brook Harker in partial fulfilment of the requirements for the degree of Master of Science.

Date April 23, 1975

ABSTRACT

In order to isolate soil factors contributing to deep plowing response on a Duagh Solonetz, two separate studies were evaluated. A deep plowing field trial which had already been under way for 6 years was examined to determine the long term effects of fertilization and/or deep plowing on the chemical analysis of soils and on alfalfa-brome production; and a greenhouse experiment was established and evaluated to determine the effect on barley yield and soil chemistry of varying depths of simulated deep plowing, extremes in soil moisture, and/or fertilization.

It was concluded that a close association of at least 2 factors appeared to be the major contribution to deep plowing response. These 2 factors constituted individual fertility and aeration responses.

Deep plowing apparently provided a more porous, open soil which was not as subject to nitrate reduction as was the normally tilled soil. Hence deep plowing appeared to provide a fertility response. While in most cases fertilization provided as large a response as did deep plowing alone; deep plowed soils experienced residual fertilizer effects not found in normally tilled soils. Deep plowing also caused a change in the chemistry of numerous soil factors such as pH, E.C. and water soluble Ca:Na ratios. Together these changes resulted in a significant yield increase.

Varying depths of deep plowing affected soil and plant analyses and yields. While in the majority of cases fertilization (NPK) was found to give as great a yield response as did simulated deep plowing; when the A horizon was retained over a B-C mix, a highly significant

yield increase over fertilization occurred. The most apparent plant analysis response to simulated deep plowing occurred in N, P and K concentration increases. A significant relationship appeared to exist between yield and the Mg content of surface soil horizons after cropping.

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INTRODUCTION

According to The System of Soil Classification for Canada (1970), soils of the Solonetzic Order are those whose B (subsurface) horizon "has a ratio of exchangeable Ca to exchangeable Na of 10 or less." Problems associated with the management of these soils for agricultural use have long been experienced (Bentley and Rost 1947, Bowser <u>et al</u>. 1962). Since nearly 5 million hectares (or almost 30%) of Alberta's arable land is Solonetzic in nature (Peters 1973) research towards the reclamation of these soils for agricultural use is of prime importance.

The disruptive effect of the Na ion on soil physical conditions has been studied extensively in an effort to explain the behavior of Solonetzic soils (MacGregor and Wyatt 1945, Arshad and Pawluk 1966, Cairns and van Schaik 1968). Many attempts have also been made to isolate other possible factors limiting production (Halstead <u>et al</u>. 1958, Cairns <u>et al</u>. 1962, Skogley and Haider 1969, Sharma 1971, Myers and McGarety 1972, Poonia and Bhmumbla 1972). Numerous factors have consequently been suggested and/or refuted as those most limiting to crop production. With suggested limiting factors have also come widely varying recommendations for reclamation procedures. Of these procedures, a reclamation method that has shown considerable promise and has consequently formed the basis for this study is that of deep plowing (Pair and Lewis 1960, Antipov - Karatayev 1965).

Basically, deep plowing consists of a disturbance of the A, B, and usually C horizons such that these horizons are displaced from

their original profile position and are mixed, resulting in the destruction of the formerly intractable B horizon. The extent to which horizons are mixed and the depth to which the profile is plowed vary widely (Fesko and Strugaleva 1959). That deep plowing alters the profile and provides crop response is beyond question (Bowser and Cairns 1967, Eck and Taylor 1969). But the irregularity with which it works (Hauser and Taylor 1964) and the specific factors responsible for deep plowing response in some Solonetzic series and lack of it in other series (Cairns 1971) are questions that have remained largely unanswered.

For the current study, a soil series was selected (Duagh Solonetz) upon which considerable research had already been done. This was done in order to benefit as much as possible from previous work. Furthermore, the specific Duagh soil sampled for greenhouse use was taken from the check plot of a deep plowing study that had already been underway for more than 6 years. This was done to enable the comparison of short term greenhouse results with those of a long term deep plowed field trial. Throughout the entire study, particular attention was paid to soil moisture content, varied soil horizon mixing, and fertilizer response in an attempt to isolate soil factors contributing to crop response on a deep plowed Duagh Solonetz.

LITERATURE REVIEW

Considerable research into deep plowing as a reclamation procedure has been carried out in the Soviet Union, the United States and in Canada.

1 - DEEP PLOWING IN THE SOVIET UNION

Maksimyuk (1958) of the Soviet Union reported the results of a 3 year study involving deep spading of Solonchak-like Solonetzes. Soils were spaded to a depth of 50 cm in order to thoroughly intermix horizons, including a portion of the gypsum rich subsoil found 35-50 cm below the surface.

The Solonchak-like Solonetzes of Maksimyuk's study had developed on a loess-like fine clay loam and consisted of four basic horizons as described by Maksimyuk: an upper solonetz horizon ranging in thickness from 5-10 cm; a solonetz horizon 20-40 cm thick having an accumulation of readily soluble salts in the lower part; a first sub-solonetz horizon 50-70 cm thick, with low moisture and low bulk density, having gypsum in the upper part; and a second sub-solonetz horizon, compacted more than the horizon above, increasing in moisture with depth, about 100 cm thick. There were few salts in the major portion of the upper two horizons. Throughout the profile $SO_4^{=}$ was the predominant anion and Na^+ the predominant cation, with maximum Cl^- concentrations corresponding with maximum Na^+. Exchangeable sodium percentage (ESP) varied from 5-12% in the upper horizons to 30-60% in the lower profile. Solonetz horizons were high in alka-

linity from carbonate and bicarbonate ions, but this decreased with depth.

Deep spading, according to Maksimyuk, created considerable chemical changes within the profile. A rough comparison of his data shows the soil solution of the surface of deep spaded soils to have increased in Cl^- milliequivalents up to 25 times that of the check, $SO_4^=$ up to 14 times, Na^+ up to 20 times, Ca^{++} 2 to 4 times, and Mg^{++} up to 6 times that of the check. Exchangeable Ca^{++} plus Mg^{++} percent was lowered by 1/2 to 1/3, while exchangeable sodium percent was raised up to 4 times that of the check. The Na^+/Ca^{++} was increased 7 times over the check surface horizon.

After spading, Maksimyuk found the rate of water intake increased 4 times over that of the check. With successive irrigations, however, a decrease in water intake gradually occurred on deep plowed soils. This was, according to Maksimyuk, due to the leaching of easily soluble salts causing a consolidation of the first sub-solonetz horizon. However, the water intake rate of deep spaded soils still remained higher than that of the check.

Maksimyuk noted that with the initiation of leaching, soil alkalinity increased in both check and deep spaded soils, supposedly due to the presence of carbonates and bicarbonates in the soil. Chloride ions were leached first, followed more slowly by $SO_4^=$, with Na_2SO_4 leaching before the less soluble $CaSO_4$. With leaching Mg^{++} content decreased markedly at first but then, according to Maksimyuk, as Ca^{++} began replacing Mg^{++} on the exchange complex the Mg^{++} content in the soil solution stabilized. Leaching lowered all ion concentrations in the soil solution except Ca^{++}.

After leaching was completed, exchangeable sodium percentages in the check soil had been reduced from an initial ESP of 30-80 down to a final ESP of 15-45. Deep spaded soils showed a similar trend but to a greater degree, being reduced from initial ESP values of 40-60 down to final ESP values of 4-5 after leaching.

Fesko and Strugaleva (1959) used deep plowing to regulate the salt and water contents of a soil varying widely from saline to Solonchak. In 1951 a road ripper with spacings 50 cm apart and working 45 cm deep was used on top of normally cultivated soils in an attempt to ameliorate them. Soils varied from weakly saline Chernozems to solonchak spots and had all developed on coarse and medium silty clay loams. The groundwater table was 2.5 m from the soil surface.

After ripping, subsoil breakage was found to be poor with profile change evident only for one year. However, moisture content continued to be higher in deep ripped plots. Infiltration in these plots was found to be higher and evaporation less than in the normally tilled soil.

Later in the study (1954), Fesko deep tilled a strongly saline soil using three tillage treatments; (a) ordinary plowing with a coulter, 25-30 cm deep; (b) deep plowing 40-45 cm deep with a subsoiler attached; and (c) deep plowing 45-50 cm deep with a subsoiler attached, but without turning over the soil. By the spring of 1955 (one year after treatment imposition) considerable compaction was evident on all deep tilled plots with little bulk density difference evident between deep and ordinarily plowed plots. After irrigation, no bulk density difference whatever was found between treatments. However, deep plowed soils froze to a shallower depth due to increased moisture

content and consequently thawed more rapidly in the spring. Also, deep plowing resulted in a uniform wetting of the top meter of the profile, whereas normal plowing resulted only in an even wetting of the surface 1/2 m, given the same amount of water. This, however, was true for the first irrigation only. With further irrigation, salt content was increasingly reduced from methods (a) through (c), while beet root and seed yields were correspondingly increased.

Botov (1959), also of the Soviet Union, obtained "Radical improvement of solonetz and podzolic soils by redistribution of soil horizons." In attempting to reclaim these soils, he plowed to a depth of 60 cm, but in so doing was careful to retain the A horizon on the surface while mixing sub-surface horizons only.

Botov makes note of the similarity of location of "limiting" horizons in both solonetzic and podzolic soils. Examining a Solonetz of the Chestnut zone he found: an upper A humus horizon, gray, 8-18 cm thick; a solonetzic B, compact when dry and sticky when wet, 15-20 cm or more thick; and a carbonate C horizon, with lime accumulation and in rare cases, gypsum. Podzols, he noted, had a surface A, a leached A_2 and an illuvial B. Similar reclamation possibilities existed for both the poor Solonetzic B and eluviated Podzolic A_2 horizons according to Botov. Both needed material from lower horizons brought up, and neither needed the surface A horizon destroyed. Botov found that by retaining the A when deep plowing Podzols, the A horizon could be thickened at less cost than that of artificially applying organic matter and fertilizers, while improving nutrient supply, moisture and aeration distribution. In Solonetzes, he found, this type of deep plowing resulted in a marked reduction of solonetzic

characteristics of the upper layer as well as a destruction and redistribution of the lower water-impermeable solonetzic layer. Both Podzols and Solonetzes were, however, found to compact with time and periodic cultivation without turning the soil was found necessary to maintain reclamation.

As mentioned, Botov performed deep plowing in such a manner as to retain the fertile A horizon on the surface while mixing sub-surface horizons. This was accomplished by using a 3 bottomed moldboard plow which, having first removed the A horizon, removed and re-distributed sub-surface horizons before re-depositing the A horizon in its original position. Through this method 90% of the humus horizon was retained on the surface 0-25 cm, the bulk of the carbonate horizon was found 25-45 cm deep, and the major solonetz horizon occurred 45-65 cm deep. Several passes with the deep plow, alternating directions, created a uniform B-C mixed layer.

II - DEEP PLOWING IN THE UNITED STATES

Considerable work has been done in the United States involving the deep tillage of both solonetzic and non-solonetzic soils.

Hauser and Taylor in Texas (1964), experimented with a slowly permeable reddish Chestnut soil to determine the effects of deep plowing. The Pullman silty clay loam used had a water infiltration rate of 5-10 cm for the first hour, 0.25 cm/hr after 4 hours and slowed further to 0.13 cm/hr after 10 hours of applying water to the soil surface. Such slow infiltration frequently prevented filling the soil moisture reservoir in a "reasonable" length of time and the authors

felt that, especially under dryland conditions, the need for more rapid infiltration and a consequent reduction in surface ponding, was essential. The Pullman profile consisted of a moderately permeable surface soil 20 cm thick, overlying a dense, compact, slowly permeable B horizon at the 20-61 cm depth, below which was found a slightly more permeable horizon. Depth to the principal caliche layer was 1.6 - 2.4 meters below the surface.

Three deep plowing treatments, as well as normal tillage, were employed by Hauser and Taylor: disc plowing to 61 cm; vertical mulching 61 cm deep on 2 m centers; and chiseling 61 cm deep on 2 m centers. Disc plowing and vertical mulching increased water infiltration 1.9 and 1.5 times that of the check, respectively, with differences evident even after 3 years. With initial irrigation, during the first 20 minutes water penetrated 2.4 meters in deep tilled plots vs. 30 cm under normal tillage. Though deep tillage significantly affected fertilized sorghum grain yields in only one of the three years, Hauser and Tayler were quick to point out that plots were irrigated so that moisture was not limiting and that plots had been diked to prevent moisture from running off the check plots before having time to infiltrate. Four years after deep tillage, bulk densities were still significantly lower (1% level) in deep tilled plots than in the check. Burnett and Hauser (1967), in a later study, concluded that generally, deep tillage to correct physical conditions probably does not improve crop yields when ample water is available. They further concluded that successful deep tillage reclamation needed both high calcium plowed to the surface and subsequent leaching.

Eck and Taylor (1969) reported the results of further deep

plowing studies on a Pullman silty clay loam. Thorough profile mixing to a depth of 90 and 150 cm increased grain sorghum yields 66 and 80%, respectively. The three year study involved pre-plant irrigation only, and deep plowing increased water use efficiency of grain 41% and that of total dry matter 25%. Results were attributed to changes in the amount and distribution of soil water and roots. Under adequate irrigation, however, profile modification had little effect upon yields, though water use efficiency was still increased in 2 of the 3 years.

Certain soils of eastern Washington and western Idaho have experienced surface waterlogging conditions in late winter and early spring (Mech et al. 1967). Considerable water movement was observed along the subsurface A_2 horizon on top of the low porosity B horizon. This led to saturated surface conditions and later possible droughty conditions due to lack of water storage in the B horizon. In an effort to correct these conditions in a Freeman silt loam - a moderately fine textured soil developed on loess under coniferous forest - deep tillage studies were carried out.

The soil under study had a 41 cm thick, slightly acid A horizon with a gray A_2 41-51 cm in depth. This A_2 was intensely leached. Below these two horizons existed a dense, high clay B horizon. Four plowing treatments (including normal tillage) were established by the authors as follows: (a) check moldboard plowing 15 cm deep; (b) complete backhoe mixing of the top 46 cm, (c) removal of surface and subsoils to a depth of 122 cm, subsequently replacing horizons in their original position; and (d) complete backhoe mixing of the A and B horizons to a depth of 122 cm. Fertilizer and non-fertilized subtreatments were applied with Ladak alfalfa being grown for 4 years.

This was followed by unfertilized wheat, to evaluate residual fertilizer effects.

Deep mixing was found to reduce bulk densities in treatments (b) and (d), while soil moisture moved progressively deeper from treatments (a) through (d). When no fertilizer was applied to treatment (d) (thorough mixing to 122 cm), more alfalfa was obtained than when treatment (a) (the check) was fertilized. Fertilizing treatment (d) further increased yields though the added nitrogen seemed to have a slight depressional effect. After harvest, alfalfa regrowth was 15 cm tall on treatment (d) while no regrowth was obtained on check tilled plots. Residual fertilizer effects on wheat resulted in two times the wheat yield on treatment (d) as on the check.

Mech <u>et al</u>. simultaneously conducted work on a soil similar to the Freeman loam but work was done at a different location and involved different treatments. In this second case, deep plowing was done with a 91 cm moldboard plow to a depth of 76-91 cm. Some poor results were explained on the basis of a possibly too severly inverted furrowed slice.

After deep plowing, the A horizon was found diagonally located between the 20 and 61 cm depth, instead of being thoroughly mixed or in a horizontal plane. Initially surface soils were severly puddled and infiltration was actually reduced. However, water and root penetration increased in the deep plowed plots and wheat roots grew profusely throughout the deep plowed zone, extracting water more rapidly and in larger amounts than in the check soil. With high fertilization, deep plowing returned a 2 year average wheat increase over the fertilized check of 1320 kg/ha. According to the authors, such wheat increases

were, however, greater than could be accounted for by increased moisture alone. Deep plowing increased grass yields only at high nitrogen rates and made no significant difference to alfalfa-grass yields.

Another soil was also deep plowed by Mech et al., one whose total A horizon depth was as great as that of deep plowing (91 cm). Little response was obtained in this case, and the authors concluded that deep plowing response varied widely with the soil and provided no improvement unless a dense subsoil was encountered during the operation.

Rasmussen et al. (1972), of SE Oregon, reported the results of deep plowing both non-saline and Solonetzic (slick spot) soils. As an ammendment $CaSO_4$ was applied as a sub-treatment and all plots were fertilized and irrigated. Treatments included: (a) an untreated check on both "slick spot" and "normal" soils; (b) deep plowing to 90 cm on both slick and normal soils; (c) deep plowing, slick soils only, to 90 cm and then adding gypsum at 18 or 36 metric tons/ha; and (d) subsoiling alone or subsoiling and adding various rates of gypsum to slick and normal soils.

Soils involved in the experiment were developed on silty alluvium with calcareous lake-laid sediments. Surface horizons were influenced by loess deposits and subsoils were non-gypsiferous but contained considerable lime. The unproductive saline-sodic (solonetz-like) soils of Rasmussen's experiment were silt loams, classed as Nadurargids. They contained a distinctive B_2 argillic (natric) horizon, low in soluble salts but moderate to high in exchangeable sodium. Lower horizons were excessive in exchangeable sodium and contained soluble salts.

Through deep plowing alone, so called "slick" soils were "chemically reclaimed" in 3-4 years. Crop yields, water intake rates, and water and root penetration were increased considerably over the check. Reclamation was also achieved through the addition of gypsum to deep tilled plots and moderate improvement was obtained through the addition of gypsum alone. Subsoiling, however, without gypsum, was not found to be beneficial. Four years of data caused Rasmussen et al. to conclude that deep plowing without added gypsum was the treatment that effectively and most economically reclaimed saline sodic (solonetz-like) soils. Deep plowing alone increased barley yields 330% over the check (1290-5530 kg/ha) and alfalfa yields 380% over the check (2.5-11.9 metric tons/ha). Before deep plowing slick soils, water penetrated 20-30 cm in 48-72 hrs and after deep plowing it penetrated to the full plow depth (90 cm) within 20-24 hrs.

Non-solonetzes of the soil association investigated by Rasmussen et al., frequently had "silica-calcium carbonate-cemented hardpan (duripan) layers-underlain by stratified layers (40 cm in depth)..." that limited water infiltration and restricted water and root penetration. Because of this restrictive subsurface horizon, these soils were also deep plowed. While results were not as striking as those found in "slick spot" soils, still, deep plowing these non-Solonetzic soils increased infiltration 12-25%, and barley yields were increased 65% over the check.

Plowing costs for all soils were placed at $88-113/ha, using a 1.2 m moldboard plow.

III - WORK AT VEGREVILLE, ALBERTA

A great deal of work towards the reclamation of the Duagh Solonetz and other Solonetzic soils has been carried out near the Agriculture Canada, Solonetzic Soil Sub-station located at Vegreville, Alberta, 110 km east of Edmonton.

Cairns (1961) published the results of a feasability study of the possible advantages of deep plowing when compared to the application of ammendments as reclamation procedures. Profile chemical characteristics of the Duagh-Wetaskiwin-Malmo Solonetzic soil sequence (Solonetz, Solodized-Solonetz, and Solod respectivily) were described in detail, it being noted that the solonetzic Duagh was the least productive and the Malmo Solod the most productive. Cairns describes these soils as generally consisting of an acid A horizon overlying an alkaline B horizon containing compact columns of varying hardness depending on the stage of pedogenesis. Below this, a C horizon high in $CaCO_3$ and with some $CaSO_4$ is found. In general, salt concentrations are low in upper horizons but increase with depth, Na_2SO_4 being the most predominant salt with $MgSO_4$ in lesser amounts. Essentially no gypsum or carbonates are found within the surface foot of soil.

Parent material for the foregoing soils consists of about 3 meters of Vermilion river deposit over till over Bear paw shale. The occurrence of readily soluble salts above less soluble salts caused Cairns to speculate that these soils are either in a state of irregular salinization, or perhaps resalinization. After an examination of alternative possibilities for amelioration, Cairns recommended deep plowing to a depth of 41-61 cm and projected costs would be less than

$50/hectare

Cairns (1962) later used a backhoe to obtain complete profile mixing of a Duagh loam to 61 cm. During the 6 year study a wheat-barley-fallow rotation was employed. Productivity of crops was generally increased during the course of the second rotation and deep plowing, on the average, was found to significantly increase crop yields. However, no relationship between productivity and the balance of soil extractable cations could be found. By the end of the study (6 years), Cairns found an intractible B horizon to have re-formed at about the same depth as the original B horizon. Concentrations of extractable calcium from areas of deep plowed soils previously occupied by A and B horizons were considerably higher than that of the check soil. Na concentrations, however, had decreased with Mg remaining unchanged. Results, according to Cairns, generally agreed with greenhouse work completed at that time.

Bowser and Cairns (1967) began a deep plowing study in 1960 on a Duagh Solonetz. The soil had a Bn horizon located at the 25-40 cm depth and was plowed to 56 cm. Cereal crops were fertilized and grown under dryland conditions with an average yearly precipitation of 40 cm (over 6 years). Precipitation for individual years varied widely though, and only a slight increase in cereal crop production was noted. However, after 6 years of small grains, alfalfa-bromegrass yield was doubled (2421 kg/ha) on deep plowed plots when compared with the check soil yields (1194 kg/ha). Bowser and Cairns found that the density of alfalfa plants was increased through deep plowing, with the depth of rooting doubled. Plants analysed were higher in Ca and K but lower in Mg and Na when grown on deep plowed soil.

Seven years after treatment imposition, Bowser and Cairns noted some vertical cleavage lines in deep plowed soils. There had, however, been no apparent movement of fine clays downward in deep plowed profiles. Also, over the years fairly good tilth had been maintained in the top 10 cm of these plots, and salts had been effectively removed to the 150 cm depth.

Much simultaneous work on Solonetzic soils of differing series has been done by Cairns to show the extreme variability existing within these soils. In one of these studies (Cairns 1970) four soils (Duagh, Torlea, Whitford, Kavanagh - described previously by Cairns) were used in a greenhouse experiment. Unfertilized alfalfa was grown under adequate moisture on Ap, Bn, and A-B-C mixed (1:1:1) horizons. One half of the horizon mix for each soil was leached with water before seeding. Mixes from 2 of the 4 soils (Whitford and Kavanagh) gave significant increases in yield when compared with Ap horizon growth. Leaching horizon mixes, however, gave no further yield increase and in two cases (Duagh and Torlea) significantly reduced yield over the Ap.

Generally, check soils were found to increase with depth in pH, electrical conductivity (E.C.) of the saturated extract, and soluble Na, while soluble Mg and K decreased. Soluble Ca also increased with depth in check soils, except in the case of the Duagh where Ap calcium exceeded Bn calcium. After mixing, horizon mixes were generally found to be higher in infiltration than their respective Bn horizons. Also, E.C. and all soluble constituents were higher in mixes than in their respective Ap horizons. Leaching mixes generally reduced E.C., pH, and soluble Mg and Na, but not to the level of the undisturbed Ap.

From plant chemical analyses, Cairns found the Na content

of alfalfa on productive mixes to be higher than that of plants grown on Ap horizons. While leaching the mixes greatly reduced subsequent alfalfa Na content, it in no case increased yield. No consistent relationship whatever could be found between yield and Ca, Mg, K or P content of alfalfa.

In a later field study by Cairns (1971), involving the same four soils (Duagh, Whitford, Torlea, Kavanagh), he concluded that on three of the Solonetzic soils, fertilizer was as effective as deep plowing in increasing yields and influencing crop chemistry. The soil having the most unproductive Bn horizon (Torlea) was found to be that giving the least fertilizer and the greatest deep plowing (56 cm) response. Once soils had been deep plowed, fertilizer response was considerably lower than that obtained on check soils. A lack of other relationships such as the retreat of soluble Na or plant moisture utilization and crop response, caused Cairns to speculate that these deep plowing responses had been partly nutritional. Through deep plowing, productivity responses of from 47-170% were obtained where one cereal and two succeeding bromegrass crops had been grown.

IV - CONCLUSIONS

Though results from deep plowing to date show considerable variation, some general trends seem evident:

1. Yield - deep plowing has provided ample evidence of yield increases. Specific factors responsible for yield increases, however, remain largely unidentified.
2. Fertility - a fertility response from deep plowing seems

evident, though some fertilizer response has been obtained even after deep plowing.

3. Parent material - in the great majority of cases reclamation through deep plowing has occurred on soils of heavy parent material.
4. Infiltration - deep plowing has consistently increased soil infiltration rates as well as depth of water and root penetration.
5. Specific ions and ion ratios - no consistent relationship between soil ion contents or ion ratios has to date been linked to plant yields. Deep plowing has drastically altered such ion concentrations.
6. Soil reaction and E.C. - deep plowing has altered pH and E.C. considerably from that of the check soil. Soils of both alkaline or acidic surface pH have benefited from deep plowing.

FIELD RESEARCH

I. MATERIALS AND METHODS

Deep plowing work on a Duagh loam near Chipman, Alberta (SE 1/4, 17-54-18-4) was begun in October, 1966 by Dr. R. R. Cairns of Agriculture Canada, Solonetzic Soil Sub-station, Vegreville, Alberta. Soil was plowed to a depth of 56 cm using a large, specially designed moldboard plow. Treatments were laid out such that one long central check strip (normal tillage) was bordered on either side by deep plowed strips. All three strips measured 9 x 150 meters.

Deep plowed and normal tillage strips were fallowed in 1967 and seeded in 1968 to alfalfa-brome with a barley companion crop. Fertilizer and no fertilizer sub-treatments were applied as cross strips (3 m in width), in triplicate, the first year of cropping. Fertilizer was rebroadcast in all succeeding crop years, except 1973 when residual fertilizer effects were tested. Application rates of 158 kg/ha of nitrogen (34-0-0 and 11-48-0), 60 kg/ha of phosphorus (11-48-0) and 139 kg/ha of potassium (0-0-60) were used. Plant yields for individual plots were recorded for all years of cropping, but plant and soil analyses were made only during later stages of the study.

Soil plots were first analysed in 1971. Extractable cations (in ammonium acetate) and other chemical analyses were determined for A, B and C horizons within the check and for similar horizon areas in deep plowed soils. Water soluble cations (saturation extract) were determined for surface horizons only. Plant samples from all plots were analysed in 1972. All analyses prior to and including 1972 were performed by Cairns.

Single soil probes were taken of individual plots on June 7, 1973

in an effort to further evaluate the long term effect of deep plowing. Soil samples were taken by horizon to a minimum depth of 90 cm. Water soluble cations (saturation extract), pH, and electrical conductivity (E.C.) were determined for all horizons.

In order to measure the effect of infiltrating water on the chemical analyses of check vs. deep plowed soils, plots were again sampled (July 5, 1973) after more than 14 cm of rain had fallen in the area. Single probes were taken as before and within 30 cm of original sampling in order to reduce variability and thereby provide valid comparisons. Samples were analysed as in the June sampling. Individual plot yields were taken at the time of this latter soil sampling, but plant samples were not chemically analysed. Plant samples of the regrowth were taken at a later date for analysis so that plant growth could be directly attributed to a known soil analysis made at the beginning of the growth period.

All chemical analyses were performed according to procedures outlined in U.S.D.A. Agriculture Handbook No. 60 (1954) with the following exceptions: acid soluble soil phosphate was extracted with 0.002 N H_2SO_4 buffered with $(NH_4)_2SO_4$ (Cairns 1961); pH in later analyses was based on a 1:2 1/2 soil water mixture to allow the calomel electrode to rest in the supernatant (Nyborg 1973); concentration of saturation extract cations was determined by atomic absorption (Isaac and Kerber 1971); and plant total N was obtained by using a Conway cell micromethod as described by Myakina (1958).

II. RESULTS AND DISCUSSION

Yield Data

Yield differences between deep plowed and normally tilled plots

over the years are found in Table 1. (Deep plowed yield values directly opposite each other from the check have been averaged since no significant difference was found between them). Comparisons can be made between unfertilized and fertilized normally tilled or deep plowed plots. The four paired comparisons indicated in the table allow all yield differences to be clearly attributed to either added fertilizer or deep plowing response.

Poor response to deep plowing in 1968 can perhaps be attributed to the fact that first season crops periodically respond differently from subsequent cropping on deep plowed soils, or to the fact that cereal response often is markedly different from that of forages on deep plowed soils (Bowser and Cairns 1967). In view of these possibilities, results for 1968 have been kept separate.

Data for 1969 - 1972 have been averaged to indicate trends that existed during 4 years of alfalfa-brome cropping under fertilization. From these data it can be seen that deep plowing clearly provided an increase in crop yields. However, added fertilizer alone is seen to have given a more significant yield response than did deep plowing alone. Such a fertilizer response leads to speculation that deep plowing is, at best, an involved method of providing only a partial fertility response. If this line of reasoning is correct, though, the question immediately arises as to why fertilized deep plowed plots yielded higher than fertilized normal tillage plots. Such yield relationships imply a benefit from deep plowing in addition to that of a possible fertility response. Results point to a close association of fertility and some other unidentified factor contributing to total deep plowing response.

Data for individual years show 1969 yields to differ from those of

Table 1. - Effect of deep plowing and/or fertilizing a Duagh Solonetz on crop yields.†

Yield as kilograms/hectare of dry matter.

Tillage	1968			1969			1970			1971			1972			1973			69-72		
	ck		NPK	ck		NPK	ck		NPK	ck		NPK	ck		NPK	ck		NPK$^{\Phi}$	ck		NPK
Normal	5313	π	8161	1301	π	4011	2330	π	4358	1879	ξ	5993	1618	ξ	3978	1268	@	3363	1782	*	4585
	@			ξ			ξ		π	@			*		π	*		*	π		@
Deep Plow	6855	@	8228	3413		4376	4535		5249	2259	ξ	5982	2615	π	4903	2618	π	5147	3205	@	5127

Yield as percent of check

Tillage	1968		69-72		1973	
	ck	NPK	ck	NPK	ck	NPK
Normal	100	154	100	257	100	265
Deep Plow	129	155	180	288	206	406

† 1968 - barley green feed, 1969 - 1973 alfalfa-brome hay.

Φ 1973 - fertilizer treatments not applied, residual effects only.

* 1% level, ξ 2% level, π 5% level, @ 10% level - T tested significant difference between values separated by symbols.

the 4 year average. Fertilized deep plowed plots show no yield increase over unfertilized deep plowed or fertilized normal tillage plots. Contrary to the four year average, deep plowing alone gave a more significant yield response than did added fertilizer alone. Yield trends for 1970 were similar to those of the previous year and again differed from the four year average where deep plowing alone was providing a more significant yield response than did fertilization alone. In 1970, however, fertilized deep plowed plots returned a significantly greater yield than did fertilized normally tilled plots. Since, in addition, no significant difference existed between unfertilized and fertilized deep plowed plots, it seems that in 1970 some deep plowing response factor other than fertility was dominant. Yields for 1971 indicate a minimal deep plowing response - indeed little response was obtained on deep plowed plots unless adequate fertilizer accompanied the treatment. In 1972, yield responses over the check were obtained for all combinations of fertilization and/or deep plowing. Data from individual years, like the four year average, point to a close association of more than one factor limiting production - the overriding factor appearing to vary with the year.

An attempt was made to determine if a relationship existed between yield response variations at Chipman (68-72) and rainfall data for individual growing seasons. Rainfall data for the immediate test site were not available and so data from the Solonetzic Soil Sub-station at Vegreville were used. Since the Duagh Solonetz is known to have a low infiltration rate it was supposed that rainfall frequency, intensity and amount during the growing season might have a definite effect upon the yield of plants grown in normally tilled vs. the more permeable (Bowser

and Cairns 1967) deep tilled plots. It was speculated that prolonged wet conditions might promote waterlogging and consequent anaerobic nitrate reducing conditions (Myers and McGarity 1972) in the check soil in contrast to the more permeable deep plowed soils. If so, these moisture and consequent fertility differences would then be reflected in yield differences. However, no consistant relationship could be found between yearly yields and area rainfall data, despite several different methods of comparison. It is recognized that rainfall data for Vegreville (50 kilometers south east of the experimental site) may have varied considerably from that of the test site - especially in intensity. Hence, differences in moisture distribution between check and deep plowed soils cannot be ruled out as a contributing factor in yield responses. (Yearly precipitation, rate of snow melt, etc., may all be contributing factors in possible moisture response differences.) It is of interest that in 1970 more than 13 cm of rainfall were recorded at Vegreville during one two week period of the growing season. This was also the year that a deep plowing response other than fertility appeared to be dominant at the test site.

While yield data for 1973 still indicate a highly significant response from deep plowing alone, residual fertilizer effects between deep plowed and normally tilled plots differed strikingly. Although data are for one year only, they lend strong support to the postulation that fertilizer was better retained and utilized in deep plowed than in normally tilled soils (Mech et al. 1967). Possible anaerobic conditions within check soils might well have depleted a nitrogen source still available within the more porous deep plowed sites.

Soil Analyses

In order to compare the earlier work of Cairns with that later done by the author and to enable meaningful comparisons between deep plowed and normally tilled plots, some data integration has been necessary. First, since samples were initially taken by depth (Cairns) and later by horizon (the author), it was found beneficial to convert all data to a horizon basis. Second, since individual horizon depths varied greatly within deep plowed soils (due to irregular deep plow mixing of original horizons), it became advantageous to lump values from small constituent horizons on a volume basis. For example, all horizons within a deep plowed profile that were below the surface horizon but above the C horizon had analysis values bulked by volume integration. This bulk value was then compared to B horizon values. The validity of such horizon value integrations is supported by later greenhouse horizon mix values (i.e. 5 cm of Ap at pH 6.2 + 7.6 cm Bnt at pH 7.1 → (Ap - Bnt) mix at pH 6.7. Volume integration predicts (5/12.6 x pH 6.2) + (7.6/12.6 x pH 7.1) = pH 6.8.) Test values on actual mixes were in all cases equal to or higher than integration predictions.

Soil analyses for 1971 are found in Table 2. Data were obtained from unfertilized plots only. Deep plowed values opposite each other from the check have been averaged since no significant difference was found between them.

Deep plowed surface horizons (5 years after plowing) were significantly greater in pH, extractable Ca, Mg, K and Na; and water soluble Mg and Na, than normally tilled Ap horizons (Table 2). The surface of deep plowed soils was found to be lower in percent P, N, and C, as would be expected due to the organic matter redistribution caused by deep plow-

Table 2. - Effect of deep plowing on the chemical properties of a Duagh Solonetz (1971), five years after plowing (1966).

Tillage	Horizon	pH 1:1	E.C.† 1:5	Meg/100 g. of Extractable Cations§ Ca	Mg	K	Na	ppm Pϕ	% N	% C	S.P.	ppm of Saturation Extractable Cationsδ Ca	Mg	K	Na
Normal	Ap	5.4	1.0	6.0	6.3	0.71	9.1	6.92	0.51	6.92	76	96	40	17	892
		*		π	π	@	π	@	π	*			@		π
Deep Plow	Surface	7.5	1.6	32.6	9.4	0.83	11.8	2.01	0.19	2.66	77	252	129	19	1548
Normal	Bnt	7.0	2.5	27.7	11.1	0.83	14.6	2.31	0.21	2.44					
							@			@					
Deep Plow	Middle	7.5	3.9	56.5	11.1	0.81	17.5	0.57	0.17	1.37					
Normal	Csk	7.9	6.2	81.9	10.3	0.79	18.3	0.86	0.04						
							π								
Deep Plow	Csk	7.7	6.4	78.5	10.5	0.78	20.7	0.75	0.04						

† E.C. in mmhos/cm
§ Extractable in ammonium acetate
ϕ Acid soluble
S.P. Saturation Percent
δ Saturation extract derived
* 1% level, π 5% level, @ 10% level - T tested significant difference between normal and corresponding deep plow values.

ing. Little other significant difference was found between deep plowed and normal tillage profiles.

A comparison of 1971 soil analyses with yield data for the same year shows the soil with the highest surface pH; highest exchangeable Ca, Mg, K, Na and water soluble Mg and Na to be the soil returning the greatest yields - the deep plowed soil. Together then, a total change in these surface horizon factors has not been unbeneficial to crop growth. While any one of the increased factors may by itself be thought to reduce crop response (i.e. increased water soluble Na), in conjunction with the rest none has by any means reduced crop growth below that of the check. This total change in surface horizons must be at least partially responsible for increased crop response on deep plowed soils. It is puzzling that so few and such small significant differences were found between factors analysed in the B horizon of the check and deep plowed middle horizon areas. It is also surprising to note the small differences existing between saturation extractable Ca and Mg concentrations or E.C. of deep plowed and normal tillage soils.

When soils were sampled in 1973 for analysis, limited classification techniques were employed. This was done in order to demonstrate the differences between deep plowed and normal tillage profiles as well as to indicate the extreme variability in horizon distribution occurring within deep plowed plots. The limited classification of plots 4, 5 and 6 (three adjacent plots) as they were found in the field is given in Table 3. The depth of deep plowing and degree of horizon mixing appear to have varied considerably from one deep plowed plot to the next. It should be visibly obvious why horizon value integrations were necessary in order to compare deep plowed values to those of the check.

Table 3. - A representative effect of deep plowing on horizon distribution (1973), 7 years after plowing (1966).†

Plot No. 4, Deep Plowed			Plot No. 5, Normal Tillage			Plot No. 6, Deep Plowed		
Depth in cm	Description	Colour	Depth in cm	Description	Colour	Depth in cm	Description	Colour
0-10	A-B-C mix. Fine, blocky structure.	2.5Y 2/1 m	0-8	Ap Medium blocky plus med. granular structure.	2.5Y 3/1 m	0-13	A-B-C mix. Fine to med. sub-angular blocky structure.	10YR 4/2
10-41	A-B-C mix. Fairly homogenous.	10YR 1.7 m with 10YR 4/3 m	8-25	Bnt Round-topped columns.	5YR 1.7/1 m	13-31	Irregular A-B-C mix. Large pockets of organic matter.	-
41-61	Csak. Undisturbed by deep plowing.	10YR 4/2 m	25-91	Csak. Gypsum rosettes. massive structure.	10YR 3/2 m	31-51	Gypsum rosettes. Little deep plowing disturbance.	10YR 4/2 m
61-91	Csak. Lime accumulation. Massive structure.	10YR 4/2 m				51-91	Csak. Many gypsum rosettes. Massive structure.	10YR 4/2 m

† Unfertilized plots.

A complete profile analysis of water soluble cations was first run in June, 1973 (Table 4). All plots were chemically analysed, but since no significant difference was found between fertilized and non-fertilized plot data, these values were bulked. Opposing deep plowed plot values were averaged as in previous comparisons.

As in the 1971 analysis, the surface pH and water soluble Mg and Na concentrations of deep plowed soils were higher than in normally tilled soils. Unlike the 1971 analyses, surface horizon Ca and E.C. were higher in deep plowed than in normally tilled soils. Deep plowing was also found to have affected the soluble cation status of the B horizon area (middle horizon). E.C. and water soluble Ca, Mg, K and Na were all significantly higher in this middle zone than in normally tilled plots. These surface and sub-surface increases found in deep plowed plots in no way reduced yields below that of the check. As in 1971, in combination if not individually, these increased factors either directly or indirectly resulted in significant yield increases.

The effect of infiltrating water on the chemical analyses of deep plowed vs. normal tillage soils can be seen from a comparison of Tables 4 and 5. Data for Table 5 were obtained after 14 cm of rain had fallen in the area. All formerly high values, with the exception of pH, were considerably reduced when surface horizons of deep plowed plots were subjected to the downward movement of water. Check soil values may be slightly higher after the rain than before, but such an increase is probably due to salts concentrating with the evaporation of a perched water table.

Table 4. - Effect of deep plowing on the chemical properties of a Duagh Solonetz (June 1973), 7 years after deep plowing (1966).†

Tillage	Horizon	Sat. %	pH 1:2½	E.C. mmhos/cm	PPM of Saturation Extractable Cations. Ca	Mg	K	Na
Normal	Ap	73	6.1	2.1	36	15	13	487
			*	*	π	π		*
Deep Plow	Surface	78	7.6	4.8	179	80	14	1124
Normal	Bnt	95	8.0	4.1	34	27	7	983
				*	*	*	*	*
Deep Plow	Middle	87	8.0	9.1	307	189	17	2231
Normal	Csk	90	8.2	10.6	371	204	21	2655
				@		@	@	
Deep Plow	Csk	88	8.4	11.2	386	224	24	2800

† Fertilized and unfertilized plot data bulked.

* 1% level, π 5% level, @ 10% level - T tested significant difference between corresponding normal and deep plow values.

Table 5. - Effect of deep plowing on the chemical properties of a Duagh Solonetz after a heavy rain (July 1973), 7 years after plowing (1966).†

Tillage	Horizon	Sat. %	pH 1:2½	E.C. mmhos/cm	PPM of Saturation Extractable Cations Ca	Mg	K	Na
Normal	Ap	71	6.7	2.3	42	27	19	573
			π	@	@			@
Deep Plow	Surface	73	7.6	3.6	86	53	12	875
Normal	Bnt	101	7.7	4.1	25	24	7	998
				*	*	*	π	*
Deep Plow	Middle	87	7.5	8.7	291	132	13	2123
Normal	Csk	96	7.4	10.8	397	167	16	1631
Deep Plow	Csk	100	7.5	10.6	405	204	18	2588

† Fertilized and unfertilized plot data bulked.

* 1% level, π 5% level, @ 10% level - T tested significant difference between corresponding normal and deep plow values.

Plant Analyses

Plants from all plots were analysed in 1972 and again in 1973 (Tables 6 and 7). Opposing deep plowed values have been averaged as in previous comparisons. Because of definite differences in the stage of physiological development between 1972 and 1973 samples, it is impossible to make between-year plant analysis comparisons. Also, plots were not fertilized in 1973 and so cannot be directly compared to fertilized samples.

Data from 1972 (Table 6) clearly illustrate the effects of fertilization and/or deep plowing on plant chemical composition. From the yield data provided it is evident that the fertilization of normal tillage plots significantly (2% level) increased alfalfa-brome yields. Plant N, P and K also increased significantly. While all other ion concentrations remained the same, fertilization enabled plants to at least maintain previous concentrations while increasing yield. When check soils were deep plowed, a significant yield response (1% level) like that obtained from fertilization, was experienced. However, there was no significant N, P or K change resulting from deep plowing. A slight change in plant Ca percent was found. Like fertilization, deep plowing allowed plants to maintain previous ion concentrations while increasing in yield. Unlike fertilization, however, deep plowing did not result in increased plant concentrations of N, P and K. Such data support the belief that deep plowing offers only a partial fertility response and that some other associated factor must also contribute to deep plowing response.

A comparison made between the analyses of plants grown on fertilized deep plowed plots and those grown on fertilized normal tillage indicates differences clearly attributable to deep plowing. From the

Table 6. - Effect of deep plowing and/or fertilizing a Duagh Solonetz on plant analysis (1972), 6 years after deep plowing (1966).

Plant analysis as percent of dry weight.

Tillage	% Ca		% Mg		% K		% Na		% N		% P		Yield kg/ha	
	ck	NPK	ck	NPK	ck	NPK	ck	NPK	ck	NPK	ck	NPK	ck	NPK
Normal	0.14	0.12	0.19	0.16	1.45 *	2.41	0.19	0.10	1.07 $^{\xi}$	1.77	0.20 $^{\pi}$	0.29	1618 $^{\xi}$	3978
	@	ξ				*							*	π
Deep Plowed	0.17	0.20	0.15	0.16	1.47 $^{\xi}$	2.06	0.11	0.09	1.09 $^{@}$	1.60	0.22	0.26	2615 $^{\pi}$	4903

ck Unfertilized

* 1% level, ξ 2% level, π 5% level, @ 10% level - T tested significant difference between values separated by symbols.

yield data it is evident that in 1972 fertilized deep plowed plots did significantly better (5% level) than fertilized normal tillage plots. Plant analyses show that plants grown on fertilized deep plowed plots maintained similar nutrient concentrations as those achieved under fertilized normal tillage - with two differences. Under fertilized conditions, deep plowing resulted in a significant increase in plant Ca percent and a significant decrease in K^+ percent. The Ca response is similar to that obtained when unfertilized soils were deep plowed, though to a greater extent. The K response, as a result of the Ca change, is expected in view of the current understanding of a relationship between Ca and K uptake (Salisbury and Ross 1969). Such explanations, nevertheless, appear unable to account for yield increases.

The analyses of plants grown on unfertilized deep plowed plots, when compared to those grown on fertilized deep plowed plots, clearly illustrate the effect of fertilization after deep plowing. As previously explained, yields were increased in 1971 through fertilizing deep plowed soils. While most nutrient levels are similar to those found in unfertilized deep plowed plots, two significant differences are evident. Fertilization after deep plowing increased plant N and K uptake. It appears that deep plowing did not fully satisfy all plant uptake requirements for these two nutrients.

Since plots were not fertilized in 1973 (Table 7), the lack of N-P-K difference between fertilized and check plots is not surprising. Of special interest, however, are the N and P differences between plants grown on previously fertilized normal tillage soils and those grown on previously fertilized deep plowed plots. While data are for one year only, the evidence clearly implies that plants grown on deep plowed

Table 7. - Effects of deep plowing and/or fertilizing a Duagh Solonetz on plant analysis (1973), 7 years after deep plowing (1966).

Plant analysis as percent of dry weight.

Tillage	% Ca		% Mg			% K		% Na			% N		% P		Yield kg/ha		
	ck	NPK	ck		NPK	ck	NPK	ck		NPK	ck	NPK	ck	NPK	ck		NPK
Normal	0.28	0.33	0.23	π	0.18	1.18	2.36	0.14	π	0.08	1.50	1.69	0.25	0.30	1268	@	3363
												π		π	*		*
Deep Plowed	0.35	0.36	0.17		0.16	2.16	2.38	0.13		0.09	1.79	1.90	0.33	0.33	2618	π	5147

ck Unfertilized
* 1% level, π 5% level, @ 10% level - T tested significant difference between values separated by symbols.

soils had a more readily available N and P source than plants grown under the same conditions, but on normally tilled soils.

III. CONCLUSIONS

Conclusions drawn from field research are as follows:

1. Yield - on the average, deep plowing did not provide as significant a yield increase in alfalfa-brome as did added fertilizer.
   - deep plowing significantly increased yields over normal tillage.
2. Deep Plowing Response - seasonal fluctuations in deep plowing response as well as plant analyses indicate a close association of fertility and some other response factor contributing to total deep plowing response. The dominant factor appeared to vary with the crop year.
3. Residual Fertilizer Effects - from one year of data, N and P appear to have been better retained and utilized in deep plowed than in normally tilled soils.
4. Soil Moisture - no consistent relationship was established between yearly yield fluctuations on deep plow vs. normal tillage plots and yearly rainfall for the general area. Rainfall data for the specific site, however, was not available and hence intensities, snow melt, etc. could not be considered.
5. Soil Analyses - after 7 years of cropping the surface horizon of deep plowed soils was generally higher in pH, E.C., and water soluble cations than was the surface of normally tilled soils. Similar differences existed between

sub-surface deep plowed and B horizons.

- higher concentrations of analysed factors in deep plowed soils in no way reduced yields below that of the check.

6. Infiltrating Water - 14 cm of rainfall caused a considerable decrease in the pH, E.C., and water soluble Ca:Na ratios of the surface horizons of deep plowed soils.

GREENHOUSE RESEARCH

I. MATERIALS AND METHODS

In order to test hypotheses suggested by the field data, a 48 pot greenhouse experiment was established. Soil from the Ap, Bnt and Csak horizons of check plot no. 5 (Table 3) was used in the six week study. Several different horizon mixes and arrangements were employed to simulate varying degrees of deep plowing. One fertility and two moisture treatments were applied, using Galt barley as a test crop.

In preparing soils for greenhouse work, samples were hand crushed while moist, then spread to air dry. After drying, remaining clods were broken with a rock crusher and all samples were ground to pass a 6 mm sieve.

Three different horizon mixes were prepared for greenhouse work, namely: (A-B), (B-C), and (A-B-C) mixes. In each case, mixes were prepared on a volume basis using average field horizon depths and average depth of C horizon deep plowed as criteria. For example, (A-B) mix was obtained by mixing A and B horizons in a 2:3 ratio, the same volume ratio in which these horizons exist in the field on the average. The (B-C) and (A-B-C) mixes were based on a 1:1 and 2:3:3 ratios respectively, since on the average an equal portion of C and B horizon had been mixed during previous deep plowing studies in the field. All mixes were made with a large canvas to assure uniform distribution. Horizons and mixes were analysed for water soluble cations (saturation extract), pH and E.C.

The soil mixes formed were used in conjunction with genetic horizons to form four different sub-treatments. This was done in order to verify the findings of Botov (1959) who had found it desirable to maintain the A horizon on the surface; and to further isolate deep plowing response

factors. Sub-treatments included: a check, A+B+C; simulated shallow plow, (A-B)+C; simulated deep plow saving the A, A+(B-C)+C; and simulated complete deep plow, (A-B-C)+C. Due to the graduation between sub-treatments, response differences are clearly attributed to the addition or deletion of a certain horizon from horizon mixes (Figure 1).

Pots employed were translucent, almost opaque plastic, 25 cm deep, with top and bottom inside diameters of 18.5 and 15 cm respectively. Of necessity, potted horizons were scaled to be 1/2 that of field A and B horizons with the remaining pot space occupied by C horizon. When C horizon was included in a mix 1/2 of the deep plowed average was incorporated and a residual 2.5 cm of C horizon was placed below the mix to simulate field conditions. Specific sub-treatment horizon depths were as follows: check = 5.08 cm Ap + 7.62 cm Bnt + 10.16 cm Csak; simulated shallow plow = 12.70 cm (A-B) mix + 10.16 cm Csak; simulated deep plow saving the A = 5.08 cm Ap + 15.24 cm (B-C) mix + 2.54 cm Csak; and simulated complete deep plow = 20.32 cm (A-B-C) mix + 2.54 cm Csak. All pots contained the same amount of A, B and C horizon soil, the only difference being the arrangement of horizons and mixes.

During the preparation of sub-treatments, horizons and horizon mixes were wetted up to 30% moisture by weight as they were added to pots. This was done in view of past experience with wetting up these soils when dry and to expedite soil moisture equilibrium. Once soils had been potted up all pots were covered to prevent evaporation and were allowed to equilibrate 14 days. At the end of this period the surface of the (A-B)+C sub-treatment was too wet to be seeded in comparison with other surface horizons and so was allowed to dry an additional 7 days while the other sub-treatments remained covered.

Sub-treatment Comparisons	Yield and analyses differences due to:
1. A+B+C (A-B)+C	(A-B) mix
2. A+B+C A+(B-C)+C	(B-C) mix
3. A+B+C (A-B-C)+C	(A-B-C) mix
4. (A-B-C)+C (A-B)+C	C in (A-B) mix
5. (A-B-C)+C A+(B-C)+C	A in (B-C) mix

Figure 1. Differentiation of sub-treatment effects attributing yield and analyses differences to the inclusion or deletion of specific horizons or mixes.

When dry enough, all sub-treatments were simultaneously seeded to 40 seeds of Galt barley per pot. Seeds were placed 2.5 cm deep and pots were maintained at 30% soil moisture while covered with filter paper until after emergence. Upon emergence the stand was thinned to 20 plants per pot and a thin layer of Perlite was placed on the surface of all pots to reduce evaporation, erosion, and the puddling effects of added water.

Three main treatments (outlined later) were imposed during the experiment, each including all 4 sub-treatments in replicates of 4, for a total of 16 pots per treatment. Immediately upon seeding, one main treatment was partially imposed by fertilizing one-third of the pots with NPK. A solution of reagent grade NH_4NO_3 and KH_2PO_4 was applied to bring the top 15 cm of each pot of the treatment to 100 ppm, 30 ppm and 40 ppm of N, P and K respectively. Three weeks into the experiment an additional 100 ppm N was added in a similar manner.

Moisture treatments were applied to complete treatment imposition. All pots were watered up to 1/10 bar moisture by weight since it was believed that such a moisture content would tend to maximize differences between check and "deep plowed" soils. It was believed that the effects of deep plowing would be emphasised when the check, due to its poor infiltration, was placed under potentially anaerobic conditions like those frequently found in the field. Two of the main treatments were finalized by allowing 2/3 of the pots (the fertilized pots and an equal treatment size of unfertilized pots) to use 1/2 of their available moisture before re-watering by weight back to the 1/10 bar percent. These treatments are hereafter referred to as the 1/10 Bar and 1/10 Bar + NPK treatments. A third treatment (Stress) was created by allowing the remaining 1/3 of pots to fall to 15 bar moisture percentage plus 10% of the available

moisture range (15 bar % + .10 (1/10 bar % - 15 bar %)) before being watered back to 1/10 bar moisture percent by weight.

Pots were randomly arranged on the center bench of a greenhouse with the air temperature maintained at 17 degrees C, with 16 hours of light per day. Visual observations of plant growth and soil-water interactions were noted.

At the end of 6 weeks photos were taken and all pots were harvested. Yield data were recorded and plant samples were chemically analysed. The surface soil of each pot from the 1/10 Bar and 1/10 Bar + NPK treatments was also chemically analysed. All analyses were performed according to methods previously described.

To determine the effect of sub-treatment on the distribution of infiltrating water, all 1/10 Bar and 1/10 Bar + NPK treatment pots were watered after harvest to 1/10 bar weight and allowed to equilibrate 2 days. Soils were then sampled at 3 equal depths (corresponding to the mid-point of A, B and C horizons respectively) and soil moisture content was determined. Profiles from these same pots were later broken down and examined to determine the effect of sub-treatment on root distribution. Observations were described according to terminology found in The System of Soil Classification for Canada (1970).

II. RESULTS AND DISCUSSION

Yield Data

After 6 weeks of barley cropping, the effects of sub-treatment or main treatment on plant growth are reflected in yield data (Table 8). (Differences between yields from 1/10 Bar and 1/10 Bar + NPK treatments are included to illustrate the yield effect of added fertilizer).

Table 8. Effect of sub-treatment or main treatment on barley yields, when grown on a Duagh Solonetz.

Yield in grams per pot

MAIN TREATMENT

Sub-treatment	Stress	1/10 Bar	1/10Bar + NPK	Yield Increase due to NPK
A+B+C	3.0 b	2.6 b	13.0 a	10.4
	b	b	b	a
(A-B)+C	1.8 a	0.6 a	4.8 a	4.2
	b	c	c	c
A+(B-C)+C	6.4 b	7.2 b	16.8 a	9.6
	a	a	a	ab
(A-B-C)+C	6.1 b	7.0 b	13.0 a	6.0
	a	a	b	bc

a>b>c by Duncans New Multiple Range Test - 1% level (5% levels were similar). Letters below values indicate statistical significance within columns, those beside values indicate significance within sub-treatments. Corresponding values having any letter in common are not significantly different.

1. Main treatments

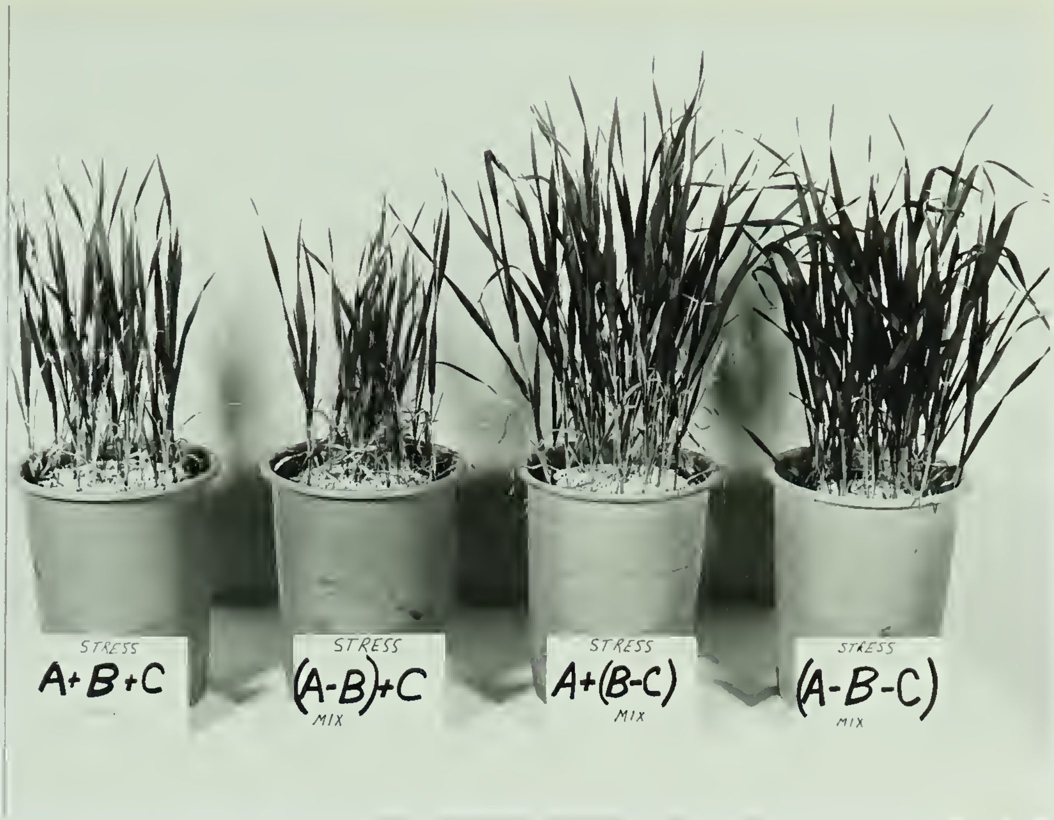
From Figure 1 and Table 8, it is apparent that within the Stress treatment, no yield benefit was obtained through mixing A and B horizons only (Plate 1). However, a significant yield increase over the check was obtained through mixing B and C or all three (A, B and C) horizons. Also, while a definite yield increase was obtained from adding C horizon to the (A-B) mix (Figure 1, point 4), no additional yield benefit occurred from including A horizon with (B-C) mix (Figure 1, point 5).

Under 1/10 bar moisture, yield results (Plate 2) were similar to those obtained under the Stress treatment. An exception was that at the higher moisture level (1/10 Bar) a significant yield reduction occurred from mixing A and B horizons only.

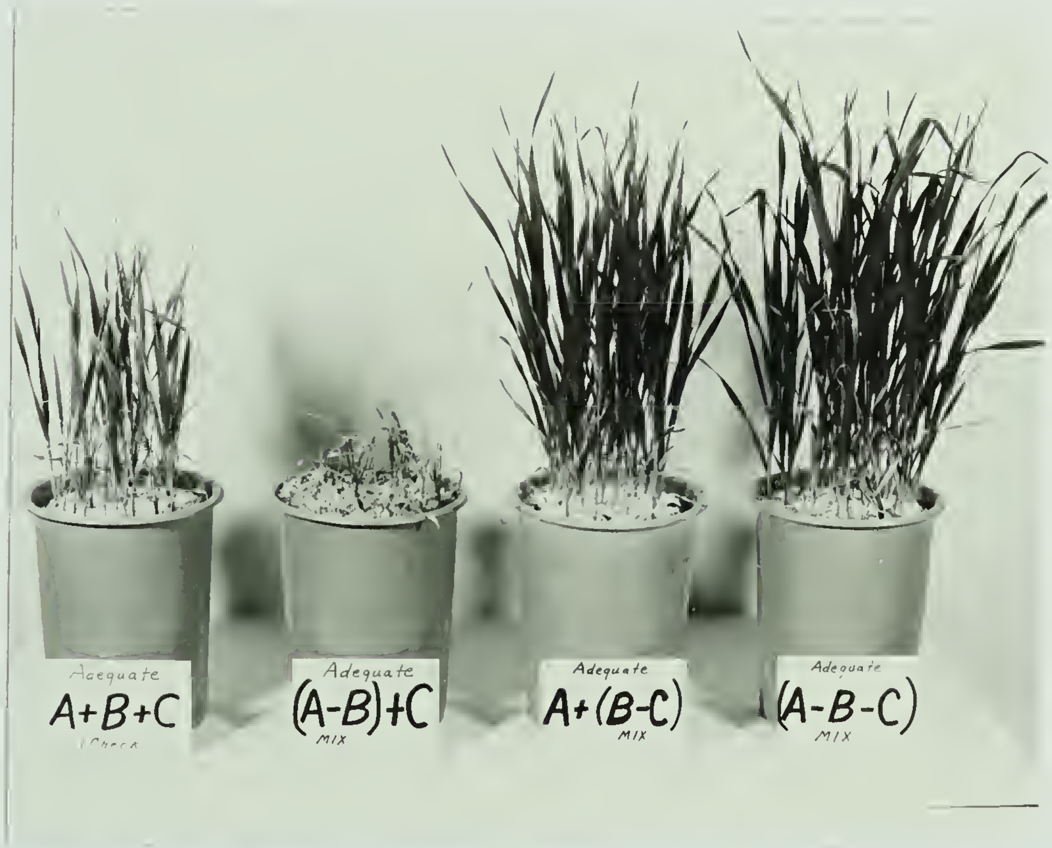
Once sub-treatments had been fertilized (1/10 Bar + NPK), a marked difference in yield response was observed (Plate 3). As with the 1/10 Bar treatment, mixing A and B horizons under fertilization was detrimental to yield response. However, once fertilized, no significant yield increase was obtained through having previously mixed A, B and C horizons. Retaining the A horizon on the surface and mixing B and C horizons still provided a significant yield response, however.

2. Sub-treatments

Comparisons among main treatments illustrate the effect (if any) on individual sub-treatment response of varying moisture and fertility. In no case did moisture differences between Stress and 1/10 Bar treatments affect yield (Plates 4-7). It is possible that wet check and (A-B) conditions within the 1/10 Bar treatment caused yield reductions equal to those caused by stressing check and (A-B)+C sub-treatments. As well, A+(B-C) and (A-B-C)+C sub-treatments may have depleted their nitrogen



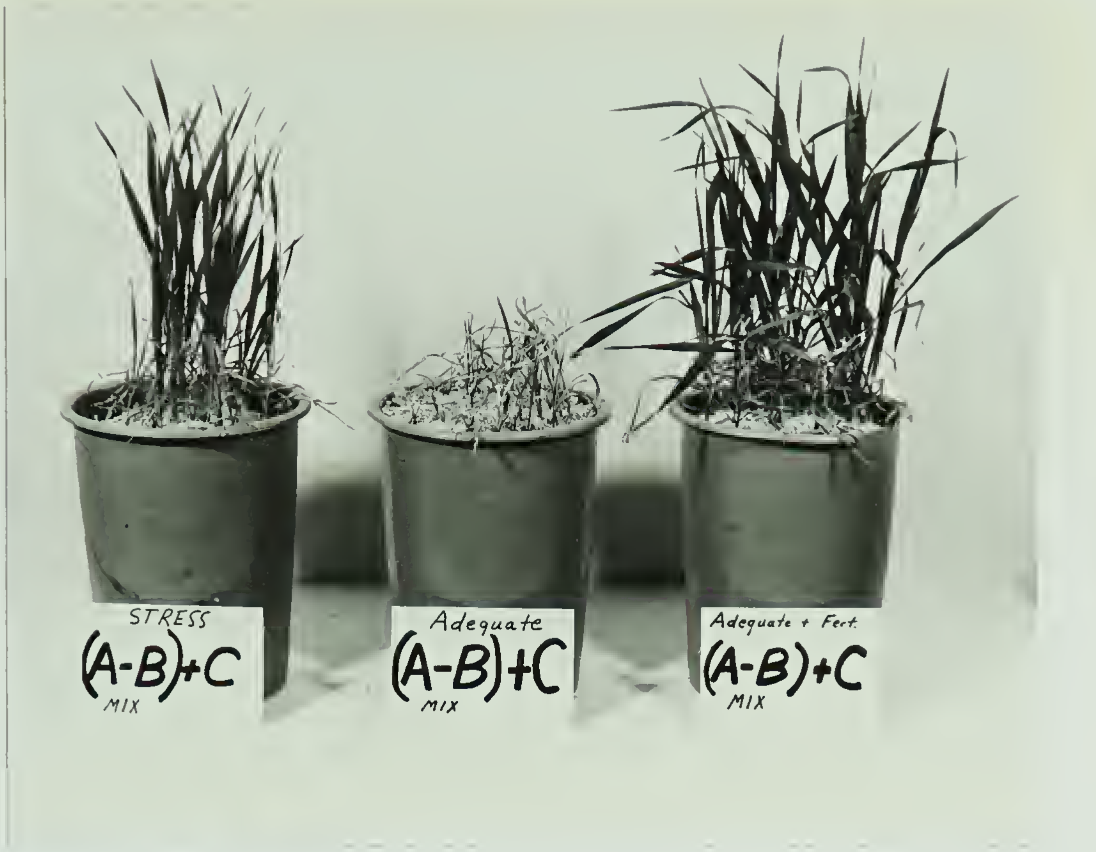
1. Effect of sub-treatment on barley growth on a Duagh Solonetz after 6 weeks under Stress treatment conditions.



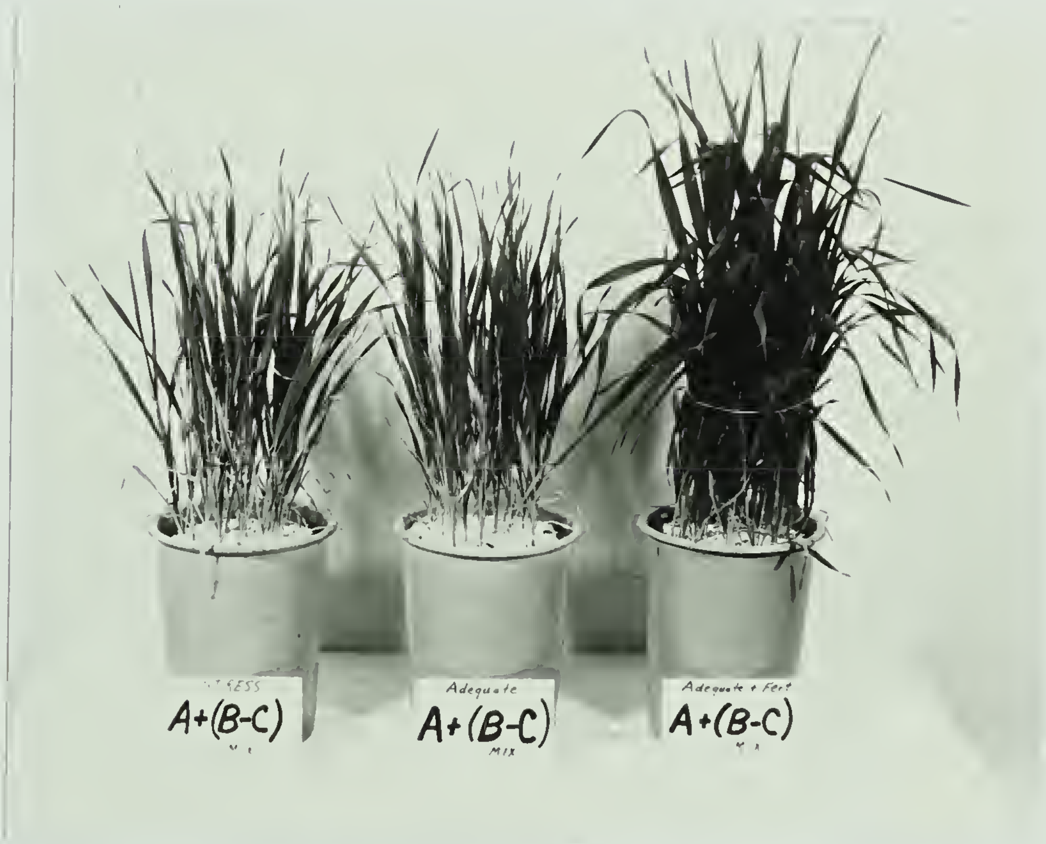
2. Effect of sub-treatment on barley growth on a Duagh Solonetz after 6 weeks under 1/10 Bar treatment conditions. (The word "Adequate" refers to 1/10 Bar moisture).

3. Effect of sub-treatment on barley growth on a Duagh Solonetz after 6 weeks under 1/10 Bar + NPK treatment conditions. (The phrase "Adequate + Fert." is more correctly 1/10 Bar + NPK).

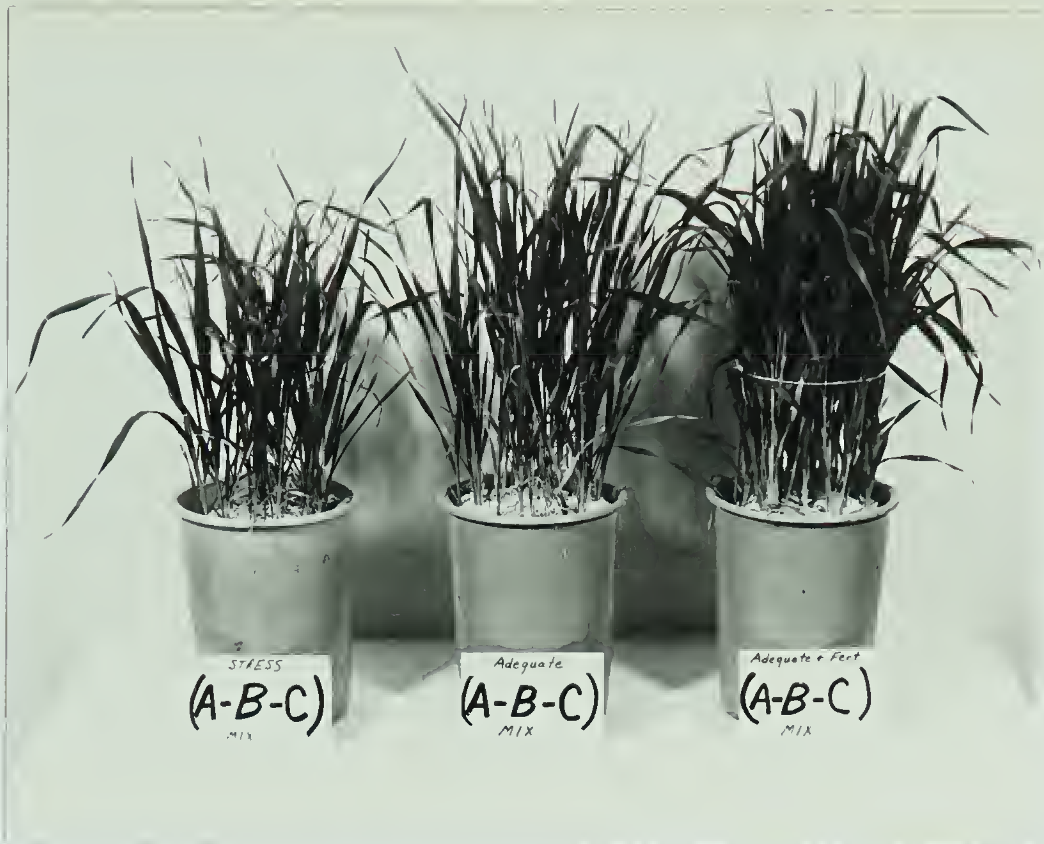
4. Effect of main treatment on 6 week barley growth on a Duagh Solonetz within the A+B+C (check) sub-treatment. ("Adequate" and "Adequate + Fert." refer to 1/10 Bar and 1/10 Bar + NPK treatments respectively).



5. Effect of main treatment on 6 week barley growth on a Duagh Solonetz within the (A-B)+C sub-treatment. ("Adequate" and "Adequate + Fert." refer to 1/10 Bar and 1/10 Bar + NPK treatments respectively).



6. Effect of main treatment on 6 week barley growth on a Duagh Solonetz within the A+(B-C)+C sub-treatment. ("Adequate" and "Adequate + Fert." refer to 1/10 Bar and 1/10 Bar + NPK treatments respectively).



7. Effect of main treatment on 6 week barley growth on a Duagh Solonetz within the (A-B-C)+C sub-treatment. ("Adequate" and "Adequate + Fert." refer to 1/10 Bar and 1/10 Bar + NPK treatments respectively).

source under the rapid growth of 1/10 bar conditions, allowing sub-treatments under stress conditions to achieve equal yield. An alternate explanation supported by visible trends in the data is that the Stress treatment never really got dry enough to cause significant yield differences between it and the 1/10 Bar treatment. Yield trends (Table 1) support the possibility that under stress conditions unfavorably wet check and (A-B)+C sub-treatments may have dried sufficiently to reduce anaerobic conditions and increase yields. Such a drying trend would be expected to have hampered A+(B-C) and (A-B-C)+C yields and data indicate a corresponding trend in that direction (Table 8).

By contrast, the addition of fertilizer (1/10 Bar + NPK) caused increased yields on all but the (A-B)+C sub-treatment (Plates 4-7).

Anaerobic Indications

1. Tilth and infiltration

Observations made during the experiment suggest possible explanations for the yields obtained. Surface tilth varied among sub-treatments, those with A horizon on the surface being the most mellow. The (A-B-C) mix had favorable surface tilth with respect to the A horizon, but the (A-B) mix tilth was very poor. When worked, the (A-B) mix formed a cloddy surface which quickly slaked upon wetting to give a puddled appearance.

Early in the experiment, differences in water intake rates among the sub-treatments became apparent. Under all three main treatments added water rapidly infiltrated into A+(B-C) and (A-B-C)+C sub-treatments, though most rapidly into the latter. However, unfertilized check and (A-B)+C sub-treatments were consistently slow to take up added water. In many cases water would pond on the surface of these sub-treatments for 2-3 hours. The surface horizons of these sub-treatments would, as

a consequence, remain saturated for several days - especially in the case of (A-B) horizons. Fertilized A+B+C and (A-B)+C sub-treatments only slightly exhibited the same trend, indicating that fertilizer may have improved infiltration (Cairns and van Schaik 1968).

2. Plant yellowing

Perhaps as a consequence of these differences in tilth and infiltration, about 3 weeks after emergence the basal leaves of many plants began to yellow - characteristically indicating a nitrogen deficiency. It became apparent that in all 3 main treatments, check and (A-B)+C grown plants were suffering. Towards the end of the experiment unfertilized A+(B-C)+C and (A-B-C)+C grown plants began to yellow as well. However, fertilized A+(B-C) and (A-B-C)+C plants never did yellow and shortly after adding the second increment of nitrogen fertilized check and (A-B)+C grown plants lost all deficiency symptoms (Plates 1-3).

In view of the infiltration differences evident between check and (A-B)+C sub-treatments and those for the simulated deep plow sub-treatments, it is consistent to believe that check and (A-B)+C sub-treatments must frequently have been under anaerobic nitrate reducing conditions probably not experienced by the A+(B-C) and (A-B-C)+C sub-treatments. The fact that check and (A-B)+C sub-treatments were the first to yellow supports such a hypothesis. It is recognized that "deep plowing" may have provided some fertility response while disallowing nitrate reduction. The yellowing of A+(B-C) and (A-B-C)+C grown plants in later stages of the experiment (Plate 2), however, is evidence that such a fertility response, if any, was not sufficient to meet plant needs for nitrogen.

The fact that even fertilized plants on check and (A-B)+C sub-

treatments experienced some nitrogen deficiency, again supports the hypothesis of reducing conditions in these sub-treatments. Since additional fertilizer soon corrected these symptoms one might be led to conclude that fertilizer could in itself provide all of the benefits of deep plowing. The equality of yields for fertilized check and (A-B-C)+C sub-treatments support this view. However, fertilizer was applied at high rates and in two applications. Before this second application deficiency symptoms were apparent in fertilized plants grown on check and (A-B)+C sub-treatments, while plants grown on "deep plowed" soils showed no such deficiency. Clearly, "deep plowed" soils provided a more efficient plant use of indigenous as well as initially added nitrogen. As with the field data, greenhouse yields and observations indicate a close association of fertility (nitrogen) and infiltration factors (improved aeration) in deep plowing response.

3. Soil moisture distribution

Moisture determinations made on all 1/10 Bar and 1/10 Bar + NPK treatment pots after cropping (Table 9) support the belief that anaerobic conditions were responsible for yield variations. 1/10 bar moisture holding capacities determined before potting-up have been listed for comparison (Table 10).

It is apparent that A, B and (A-B) horizons would not be expected to differ in moisture content once watered pots had reached equilibrium (Table 10). All 3 horizons would, however, be expected to differ from an (A-B-C) surface horizon. Moisture determinations after 2 days of equilibrating in pots, indicated this to be the case. If pots had reached equilibrium, middle horizon B and (A-B) soils would be expected to be significantly higher in moisture than (B-C) and (A-B-C) soils.

Table 9. Effect of sub-treatment on 1/10 bar moisture values after 6 weeks of cropping with barley.

Soil moisture determinations in percent.

	Horizon or Mix Profile Position			
Sub-treatment	Surface		Middle	Lower
A+B+C	77 a	*	50 a	46 a
(A-B)+C	82 a	π	55 a	46 a
A+(B-C)+C	76 a	*	45 a	46 a
(A-B-C)+C	54 b		49 a	48 a

a>b Values within columns, having a common symbol, are not significantly different by Duncans New Multiple Range Test at the 1% level.

* 1% level, π 5% level. Corresponding surface and middle horizon values separated by a symbol have been T tested significantly different at the indicated levels.

Table 10. Effect of horizon or horizon mix on 1/10 bar moisture value, before potting up.

1/10 Bar moisture values

Horizon	Percent	Mix	Percent
A	66%	(A-B)	69%
B	67%	(B-C)	53%
C	48%	(A-B-C)	51%

This was not found to be so. A significant difference was not found between the middle horizon moisture content of any pots, indicating that moisture had not penetrated through B and $(A-B)_2$ horizons.

From prior 1/10 bar moisture determinations (Table 10) it is evident that if soil horizons had reached equilibrium, a comparison of surface to middle horizons within check, (A-B)+C and (A-B-C)+C sub-treatments respectively, should indicate little significant moisture difference between these two horizons of individual sub-treatments. The surface and middle horizon areas within A+(B-C)+C pots would, however, be expected to differ significantly. A T test comparison of surface to middle horizons within all pots showed this to be only partially true. As expected, the surface and middle horizons of the A+(B-C)+C sub-treatment were significantly different while those of the (A-B-C)+C sub-treatment were not. However, surface horizons of A+B+C and (A-B)+C sub-treatments were significantly greater in water content than were their middle horizon areas, again indicating the existence of a perched water table.

Since moisture determinations were made from the center (mid depth) of middle horizons it is impossible to know whether these horizons were less wet because their own surface portions were sealing or because upper horizons were not allowing moisture to reach them, or a combination of both. That the A horizons of both check and A+(B-C)+C sub-treatments were higher in moisture than expected lends support to the first argument. However, moisture was found penetrating (B-C) horizons while not doing so in B horizons, supporting the argument that the B horizon had apparently sealed off infiltrating water.

Another support of the evidence of differences in water distribution and consequent aeration differences among sub-treatments is seen through

differences in root distribution (Table 11). Obvious differences between A+B+C and (A-B)+C and "deep plowed" sub-treatments are evident, with more roots going deeper in sub-treatments that had the C horizon mixed.

Soil Analyses

1. Effect of horizon mixing

Soils were chemically analysed in an effort to explain yield variations and the results of analyses before cropping are found in Table 12. (In order to appreciate the significance of changes that occurred in soil chemistry through mixing, the comparative chart in Figure 1 is useful. Differences in yield data among unfertilized sub-treatments (1/10 Bar) also help in making comparisons).

From the data, mixing A and B horizons raised the pH, E.C., and soluble Na and widened the soluble Ca:Na ratio when compared to the A horizon, while lowering the saturation percent and pH and narrowing the soluble Ca:Na ratio with respect to the B horizon. The wide Ca:Na ratio (1:27) and the consequent puddling of the (A-B) mix appear to have negated any possible benefits obtained from mixing, however, since plants grown on the (A-B) mix (1/10 Bar) yielded lower than those grown on the check sub-treatment (Table 8).

When B and C horizons were mixed the analyses of the mix changed considerably from that of the B horizon (Table 12), but changed only slightly from that of the C horizon. Through mixing, the saturation percent with respect to the B horizon was decreased 23%, E.C., soluble Ca, Mg and Na were all spectacularly increased and the soluble Ca:Na ratio was narrowed to less than 1/6 of it's original B horizon value (from 1:40 to 1:6). The physical features of such a mix would be expected to have improved considerably over those of the former B.

Table 11. Effect of sub-treatment or main treatment on root growth of 6 week barley grown on a Duagh Solonetz.†

		1/10 Bar Main Treatment		1/10 Bar + NPK Main Treatment	
Sub-treatment	Horizon	Root Abundance	Root Orientation	Root Abundance	Root Orientation
A+B+C	A	Plentiful	Random	Abundant	Random
	B	Plentiful	Random	Plentiful	Random
	C	Very Few	Vertical	Very Few	Vertical
(A-B)+C	$(A-B)_1$	Plentiful	Random	Plentiful	Random
	$(A-B)_2$	Few	Random	Plentiful	Random
	C	Very Few	Vertical	Very Few	Vertical
A+(B-C)+C	A	Plentiful	Random	Abundant	Random
	$(B-C)_1$	Plentiful	Random	Plentiful	Vertical
	$(B-C)_2$	Plentiful	Vertical	Plentiful	Vertical
(A-B-C)+C	$(A-B-C)_1$	Plentiful	Random	Plentiful	Random
	$(A-B-C)_2$	Plentiful	Rand.-Vert.	Plentiful	Vertical
	$(A-B-C)_3$	Plentiful	Vertical	Plentiful	Rand.-Vert.

† Descriptive terms are as used in the System of Soil Classification of Canada.

Table 12. Effect of horizon mixing on the chemical analyses of a Duagh Solonetz.

			Average of Two Replications					
				ppm of Saturation Extractable Cations				
Horizon or mix	S.P.	pH 1:2½	E.C. mmhos/cm	Ca	Mg	K	Na	Ca:Na
A	79^{ab}	6.2^{f}	1.8^{d}	18^{b}	14^{d}	16^{ab}	375^{c}	$1:21^{c}$
B	88^{a}	7.2^{d}	3.2^{c}	20^{b}	17^{d}	4^{c}	775^{b}	$1:40^{a}$
C	80^{ab}	8.6^{a}	10.4^{a}	465^{a}	209^{c}	16^{ab}	3100^{a}	$1:7^{d}$
(A-B)	72^{b}	6.8^{e}	3.5^{c}	25^{b}	15^{d}	8^{bc}	675^{b}	$1:27^{b}$
(B-C)	68^{b}	7.7^{b}	10.0^{ab}	475^{a}	262^{b}	14^{abc}	3062^{a}	$1:6^{d}$
(A-B-C)	69^{b}	7.4^{c}	10.2^{ab}	462^{a}	284^{a}	20^{a}	3088^{a}	$1:6^{d}$

S.P. Saturation Percent

a>b>c>d>e>f Values within individual columns having any letter in common are not significantly different by Duncans New Multiple Range Test - 1% level.

Mixing B and C horizons dropped the pH of the new mix below that of the C horizon. Mixing also caused a slight increase in soil Mg concentrations. A definite yield advantage was obtained through the mix (Table 8).

Completely mixing A, B and C horizons produced chemical changes similar to those caused by the (B-C) mix. Of course this complete mix resulted in considerable increases in all values when compared with the A horizon ratio. The yield advantage obtained through mixing was similar to that achieved through mixing B and C horizons only (Table 8).

2. Effect of cropping

Through cropping the surface horizons of both A+B+C (check) and (A-B)+C sub-treatments were increased in soluble Ca and Na (compare Tables 12 and 13). However, increases were such that the final Ca:Na ratio was more favorable than before cropping. The pH remained unchanged. The change in the composition of the A horizon of the A+(B-C) sub-treatment was striking. All values were drastically altered with cropping, including pH, and the former Ca:Na ratio of 1:21 was narrowed to 1:6. The change in soluble constituents is attributed to crop nutrient recycling (Salisbury and Ross 1969) from the concentrated (B-C) mix and to the upward movement of salts with capillary rise. The lowering of pH is accounted for on the basis of increasedleaching due to the more porous (B-C) horizon having replaced the former B horizon. Due to the high salt content of the (A-B-C) mix only a small change resulted from cropping.

3. Effect of fertilization

The rate of solodization (Bentley and Rost 1947) increased through fertilizing the A+B+C sub-treatment as evidenced by a significant narrowing of the Ca:Na ratio (Table 13). Through fertilization the E.C. of the A+B+C sub-treatment was raised to a level commonly considered

Table 13. Effect of main treatment on the chemical analyses of surface soils after 6 weeks of barley cropping.

Sub Treatment	Main Treatment	1:2½ pH	E.C.@	ppm of Saturation Extractable Cations Ca	Mg	K	Na	Ca:Na
	1/10 Bar	6.2	3.6	54	53	22	850	1:16
A+B+C		*	*	*	*		*	
	1/10 Bar + NPK	5.2	8.1	338	230	28	2181	1:6
	1/10 Bar	6.7	4.6	57	59	13	1208	1:21
(A-B)+C		*	π	*	π			
	1/10 Bar + NPK	6.3	6.4	139	121	19	1542	1:11
	1/10 Bar	5.5	10.1	494	281	42	2894	1:6
A+(B-C)+C		*						
	1/10 Bar + NPK	5.2	9.9	513	316	42	2700	1:5
	1/10 Bar	8.1	9.6	619	218	16	2862	1:5
(A-B-C)+C								
	1/10 Bar + NPK	8.0	9.6	563	217	17	2850	1:5

@ E.C. in mmhos/cm

* 1% level, π 5% level - values separated by symbols are significantly different from corresponding values within the same sub-treatment. No statistics were run on Ca:Na ratios.

detrimental (U.S.D.A. Agriculture Handbook No. 60 1954) while the pH fell as expected. Yields, however, were significantly increased (Table 8). The majority of (A-B) values were also changed through fertilization, though pH and E.C. extremes were not as great. Once soils had been deep plowed (simulated), fertilization caused little change in addition to that already caused by cropping.

4. Effect of sub-treatment

Within the 1/10 Bar treatment, after cropping only slight differences in chemical analyses occurred between the surfaces of check and (A-B)+C sub-treatments (Table 14). While the check soil had the lower pH, it also had a lower E.C. and a narrower Ca:Na ratio which together or individually may account for yield differences. A comparison of the surface horizons of A+B+C and A+(B-C)+C sub-treatments strikingly illustrates the effect of sub-treatment on soil chemical changes with cropping. Initially, these two surface horizons were equal in all respects, but due to sub-treatment differences, cropping caused significant differences in all analyses. Comparisons of A+(B-C)+C and (A-B-C)+C sub-treatments show an opposite sub-treatment effect. Where once the surface horizons of these two sub-treatments differed in almost every respect, after cropping, their chemical properties approached similarity.

In general, it appears that the surface soils with the highest E.C., Ca, Mg, Na, and narrowest Ca:Na ratio were also those that returned the highest yield (Tables 14 and 8). It is evident that in conjunction with other factors neither high soluble Na nor high E.C. was detrimental to the point of reducing yield below that of the check. As well, both high and low pH values were tolerated when in conjunction with the other factor values noted.

Table 14. Effect of sub-treatment on the chemical analyses of surface soils, after 6 weeks of barley cropping.

Treatment	Sub-treatment	S.P.	pH 1:2½	E.C. mmhos/cm	ppm of Saturation Extractable Cations Ca	Mg	K	Na	Ca:Na
	Duncans Test --	5% 1%	5% 1%	5% 1%	5% 1%	5% 1%	5% 1%	5% 1%	
1/10 Bar	A+B+C	b 77 b	c 6.2 c	c 3.6 b	c 54 b	b 53 b	b 22 b	b 850 b	1:16
	(A-B)+C	b 73 b	b 6.7 b	b 4.6 b	c 57 b	b 59 b	b 13 b	b 1208 b	1:21
	A+(B-C)+C	a 78 a	d 5.5 d	a 10.1 a	b 494 a	a 281 a	a 42 a	a 2894 a	1:6
	(A-B-C)+C	b 72 b	a 8.1 a	a 9.6 a	a 619 a	a 218 a	b 16 b	a 2862 a	1:5
1/10 Bar +NPK	A+B+C	b 74 b	c 5.2 c	b 8.1 ac	b 338 b	b 230 b	b 28 b	b 2181 ac	1:6
	(A-B)+C	b 75 ab	b 6.3 b	c 6.4 c	c 139 c	c 121 c	c 19 b	c 1542 c	1:11
	A+(B-C)+C	a 80 a	c 5.2 c	a 9.9 a	a 513 a	a 316 a	a 42 a	a 2700 a	1:5
	(A-B-C)+C	b 72 b	a 8.0 a	a 9.6 a	a 563 a	b 217 b	c 17 b	a 2850 a	1:5

a>b>c>d Values within the same treatment and column, followed by any letter in common, are not significantly different (1% level), by Duncans New Multiple Range Test. Ca:Na ratios were not tested.

S.P. Saturation Percent

Within the 1/10 Bar + NPK treatment yield differences (Table 8) were generally varied from those of the unfertilized 1/10 Bar treatment and soil analyses were separately examined accordingly (Table 14). Unlike the 1/10 Bar treatment, significant differences existed between the chemical analyses of the surface horizons of check and (A-B)+C sub-treatments. The surface of the check soil was higher in Ca and Mg and had a lower Ca:Na ratio than the (A-B) surface soils. Yield and pH trends between these two sub-treatments were similar to those obtained in the 1/10 Bar treatment.

Unlike the 1/10 Bar treatment, once fertilized, the surfaces of A+B+C and A+(B-C)+C treatments did not significantly differ in Na, pH, E.C. or Ca:Na ratio (at the 1% level). A comparison of check and (A-B-C)+C surfaces also shows that significant differences no longer existed among Mg, Na, E.C. or Ca:Na values. From the comparisons made in Table 13 it is evident that fertilizer caused a large change in the check sub-treatment which resulted in the observed change in sub-treatment differences. Where once the surface horizons of check and A+(B-C) and (A-B+C) sub-treatments differed significantly, fertilization greatly decreased the number of those differences. As in the 1/10 Bar treatment, under fertilization the A+(B-C)+C sub-treatments seems to have had a concentrating effect on surface horizon K concentration.

A direct relationship appears to exist between final soil Mg content and plant yield. This relationship generally holds true under 1/10 Bar conditions as do several soil factors, but was directly correlated under the 1/10 Bar + NPK treatment. Soil Ca followed closely. As in the 1/10 Bar treatment, pH and E.C. in conjunction with other factors cannot be depressing yield below that of the check. The fact that check and

(A-B-C)+C sub-treatments both had the same yield but widely differing final pH values supports this reasoning as well as the fact that A+B+C and A+(B-C)+C sub-treatments both had the same final pH but differing yields. The highest yielding sub-treatments were again those with the highest surface E.C.

Plant Analyses

The results of plant analyses are contained in Tables 15, 16 and 17. Yield data have been included to ascertain if a relationship exists between yield and plant analyses.

1. Effect of sub-treatment

Table 15 shows the effect of sub-treatment variation upon plant composition within a main treatment. The comparative chart (Figure 1) facilitates the determination of differences due to sub-treatments variation.

Within the Stress treatment, it is evident that mixing A and B horizons caused little change in plant chemistry as compared with the check. Plant K was reduced significantly (1% level) with % N increasing somewhat (5% level). No yield difference was achieved. Though mixing B and C horizons caused a substantial yield increase, again plant chemistry changes were few with the only major change over the check being that of a total N increase. Less significant increases (5% level) occurred in Mg and K concentrations. Mixing all 3 (A, B and C) horizons caused a yield increase like that of simply mixing B and C horizons, but a much larger chemical change occurred in plant composition through this more complete mix. Plants grown on an (A-B-C) mix significantly increased over the check in total N and % K (1% level) while making less significant increases in % Ca, % Na and % N.

Table 15. Effect of sub-treatment on the chemical analyses of 6 week old barley plants grown on a Duagh Solonetz.

Treatment	Sub-treatment	% Ca			% Mg			% Na			Total N mg			% N			% P			% K			Yield g.		
	Duncans Test →		5%	1%		5%	1%		5%	1%		5%	1%		5%	1%		5%	1%		5%	1%		5%	1%
Stress	A+B+C	0.22	b	a	0.27	b	a	3.11	bc	a	55	c	c	1.84	b	a	0.29	ab	ab	1.00	c	b	3.0	b	b
	(A-B)+C	0.20	b	a	0.25	b	a	4.15	ab	a	47	c	c	2.73	a	a	0.17	b	b	0.76	d	c	1.8	b	b
	A+(B-C)+C	0.37	ab	a	0.34	a	a	3.94	ab	a	127	b	b	2.01	b	a	0.28	a	ab	1.18	b	b	6.4	a	a
	(A-B-C)+C	0.48	a	a	0.30	ab	a	4.35	a	a	198	a	a	3.27	a	a	0.34	a	a	1.43	a	a	6.1	a	a
1/10 Bar	A+B+C	0.18	c	b	0.22	ab	ab	3.09	b	bc	38	c	c	1.57	b	bc	0.17	b	b	0.66	b	b	2.6	b	b
	(A-B)+C	0.20	c	b	0.20	bc	bc	4.50	a	a	12	d	d	2.17	a	ab	0.06	c	c	0.17	c	c	0.6	d	c
	A+(B-C)+C	0.32	b	a	0.24	a	a	2.65	c	c	100	b	b	1.43	b	c	0.29	a	a	1.32	a	a	7.2	a	a
	(A-B-C)+C	0.37	a	a	0.22	ab	ab	3.35	b	b	179	a	a	2.56	a	a	0.30	a	a	1.38	a	a	7.0	a	a
1/10 Bar + NPK	A+B+C	0.30	b	b	0.20	ab	a	2.83	c	c	401	b	a	3.08	b	b	0.31	a	a	1.77	ab	ab	13.0	b	b
	(A-B)+C	0.38	b	ab	0.21	a	a	4.56	a	a	187	c	c	3.76	a	a	0.33	a	a	9.98	c	c	4.8	c	c
	A+(B-C)+C	0.31	b	b	0.19	b	a	3.26	c	bc	520	a	a	3.11	b	b	0.35	a	a	1.86	a	a	16.8	a	a
	(A-B-C)+C	0.45	a	a	0.20	ab	a	3.87	b	b	446	ab	a	3.44	ab	ab	0.38	a	a	1.75	ab	ab	13.0	b	b

a>b>c>d Values within the same treatment and column, having any letter in common, are not significantly different by Duncans New Multiple Range Test, at the levels indicated (5% or 1%).

Comparing (A-B-C)+C and (A-B)+C sub-treatments helps differentiate the effect upon plant chemistry of including C horizon in the mix under stress conditions. By including C horizon a significant yield increase was obtained and a slight increase in plant Ca content resulted as well as highly significant increases in total N, % P and % K. Evidently, including the C horizon provided an N, P and K benefit.

A comparison of (A-B-C)+C and A+(B-C)+C sub-treatments illustrates the effect of incorporating A horizon in the mix. Including the A horizon increased plant K and N but did not simultaneously increase yield.

Within the 1/10 Bar main treatment, the effect of sub-treatment variation on plant composition can again be assessed using the comparative chart (Figure 1). Mixing A and B horizons depressed yields with highly significant decreases in total N and plant P and K. A slight increase in % N and a large increase in % Na also occurred. As in the Stress treatment, mixing B and C horizons resulted in a yield increase and plant composition change. Significant increases in plant Ca, total N, % P and K occurred accompanied by a slight decrease in plant Na.

When check and (A-B-C)+C sub-treatments are compared complete horizon mixing is found to have caused a yield increase and chemical change in plants like that caused by the (B-C) mix. Once again, plant total N, % P and K had been increased. An increase in % N also occurred.

A comparison of (A-B-C) and (A-B) plant values illustrates how incorporating C horizon into the mix caused significant increases in yield, plant Ca, total N and plant P and K while significantly reducing % Na. (A-B-C) and (B-C) comparisons show that incorporating A horizon into the mix has caused significant increases in plant Na, % N and total N with only a slight increase in plant Ca but no yield increase.

Within the 1/10 Bar + NPK treatment, mixing A and B horizons again caused a reduction in yield with plant chemistry changing as in the 1/10 Bar treatment. Decreases in % K and total N resulted, with % Na and % N increasing. Mixing B and C horizons significantly increased yield as in the other main treatments but a slight increase occurred in total N only.

Unlike the other sub-treatments, mixing A, B, and C horizons did not cause a significant yield increase within the 1/10 Bar + NPK treatment. Significant increases over the check in plant Ca and Na were, however, obtained.

A comparison of (A-B-C)+C and (A-B)+C sub-treatments reveals the effect of incorporating C horizon into the mix. From such an incorporation a definite yield response was obtained along with increases in total N and plant K and a slight Ca increase. Na content was reduced through such a mix. (A-B-C)+C and A+(B-C)+C comparisons illustrate that incorporating A horizon into a mix within the 1/10 Bar + NPK treatment caused an increase in Ca and a less significant Na increase. Yields were depressed.

A comparison of plant chemical differences directly caused by fertilization (Table 16) allows a comparison of sub-treatment differences showing where significant composition changes occurred.

A comparison of A+B+C and (A-B)+C sub-treatments shows that the only significant difference between the two plant compositions, caused by fertilizer, was in total N uptake. Fertilizer caused a more significant total N increase in the check than in the (A-B)+C sub-treatments. Fertilizer induced yield increases account for this.

Fertilizer caused a greater increase in plant % N in the A+(B-C)+C than in the A+B+C (check) sub-treatment. The same trend is visible when

Table 16. Effect of sub-treatment on the change in plant analyses due to the fertilization of barley, grown 6 weeks on a Duagh Solonetz.

Change in plant analysis as percent of plant composition

Sub-Treatment	% Ca	% Mg	% Na	Total N mg	% N	% P	% K
A+B+C	0.12^{ab}	-0.02^{ab}	-0.28^{b}	362^{a}	1.51^{a}	0.15^{ab}	1.11^{a}
(A-B)+C	0.17^{a}	0.01^{a}	0.06^{ab}	175^{b}	1.59^{a}	0.28^{a}	0.86^{ab}
A+(B-C)+C	0.00^{b}	-0.05^{b}	0.62^{a}	420^{a}	1.67^{a}	0.06^{b}	0.55^{ab}
(A-B-C)+C	0.08^{ab}	-0.02^{ab}	0.52^{a}	267^{ab}	0.88^{a}	0.09^{b}	0.37^{b}

a>b Values within the same column having any letter in common are not significantly different by Duncans New Multiple Range Test – 1% level.

A+B+C and (A-B-C)+C sub-treatment results are compared. However, in the latter comparison fertilization caused substantially less K to accumulate in (A-B-C)+C grown plants than in the check grown plants.

In general, changes in plant chemistry entirely due to fertilizer appear to have been negligible between check and (A-B) sub-treatments. Fertilizer affected both A+(B-C)+C and (A-B-C)+C sub-treatments similarly, increasing % Na in both more than in the check. However, K was not increased in plants grown on the (A-B-C)+C sub-treatment as much as in check grown plants. Of interest, % N and % P response was not greater in sub-treatments when compared to the check. A comparison of (A-B-C)+C and (A-B)+C sub-treatment response to fertilizer shows both responding similarly except in % P. The (A-B-C)+C sub-treatment showed less % P response through fertilization. A comparison of (A-B-C)+C and A+(B-C)+C sub-treatments shows no difference in fertilizer response.

2. <u>Effect of main treatment</u>

Table 17 shows the effect of main treatment variation upon the plant analyses of individual sub-treatments.

A comparison of Stress and 1/10 Bar treatments illustrates how widely differing moisture treatments affected the chemical status of plants grown on different sub-treatments. Within the A+B+C sub-treatment a significant difference in plant Mg content and less significant differences in P and K were obtained through varying soil moisture. No simultaneous yield difference occurred. Results from varying moisture within the (A-B)+C sub-treatments were similar in analysis and yield. Differences between A+(B-C)+C grown plants varied from those of the check and (A-B)+C sub-treatments. Within this sub-treatment changes in moisture altered Mg as before but did not change P. Significant changes occurred in

Table 17. Effect of Main treatment on the chemical analyses of 6 week old barley plants grown on a Duagh Solonetz.

Sub-treatment	Treatment	% Ca		% Mg		% Na		Total N mg		% N		% P		% K		Yield g.	
	Duncans Test →	5%	1%	5%	1%	5%	1%	5%	1%	5%	1%	5%	1%	5%	1%	5%	1%
		ab	a	a	a	a	a	b	b	b	b	a	a	b	b	b	b
	Stress	0.22		0.27		3.11		55		1.87		0.29		1.00		3.0	
		b	a	b	b	a	a	b	b	b	b	b	a	c	b	b	b
A+B+C	1/10 Bar	0.18		0.22		3.09		38		1.57		0.17		0.66		2.6	
		a	a	b	b	a	a	a	a	a	a	a	a	a	a	a	a
	1/10 Bar + NPK	0.30		0.20		2.83		401		3.08		0.31		1.77		13.0	
		b	b	a	a	a	a	b	a	b	ab	b	b	a	ab	ab	a
	Stress	0.20		0.25		4.15		47		2.73		0.17		0.76		1.8	
		b	b	b	b	a	a	b	a	b	b	c	b	b	b	b	a
(A-B)+C	1/10 Bar	0.20		0.20		4.50		12		2.17		0.06		0.17		0.6	
		a	a	b	ab	a	a	a	a	a	a	a	a	a	a	a	a
	1/10 Bar + NPK	0.38		0.21		4.56		187		3.76		0.33		0.98		4.8	
		a	a	a	a	a	a	b	b	b	b	b	b	c	b	b	b
	Stress	0.37		0.34		3.94		127		2.01		0.28		1.18		6.4	
		a	a	b	b	b	b	b	b	c	b	b	b	b	b	b	b
A+(B-C)+C	1/10 Bar	0.32		0.24		2.65		100		1.43		0.29		1.32		7.2	
		a	a	b	b	b	ab	a	a	a	a	a	a	a	a	a	a
	1/10 Bar + NPK	0.31		0.19		3.26		520		3.11		0.35		1.86		16.8	
		a	a	a	a	a	a	b	b	a	a	ab	ab	b	b	b	b
	Stress	0.48		0.30		4.35		198		3.27		0.34		1.43		6.1	
		a	a	b	b	c	c	b	b	b	b	b	b	b	b	b	b
(A-B-C)+C	1/10 Bar	0.37		0.22		3.35		179		2.56		0.30		1.38		7.0	
		a	a	c	b	b	b	a	a	a	a	a	a	a	a	a	a
	1/10 Bar + NPK	0.45		0.20		3.87		446		3.44		0.38		1.75		13.0	

a>b>c Values within the same sub-treatment and column, having any letter in common, are not significantly different by Duncans New Multiple Range Test, at levels indicated (5% or 1%).

plant Na % with less significant changes in plant K and % N. However, no yield difference resulted. Plant variations occurring within the (A-B-C)+C sub-treatment were similar to the A+(B-C)+C results though % N changes were more significant and no K change occurred.

It appears that extremely low and extremely high moisture percentages (i.e. Stress vs. 1/10 Bar) similarly affected yields and the composition of plants grown on check and (A-B) sub-treatments. The effect of moisture variation on plant Mg content was similar in "deep mixed" sub-treatments to that found in check and (A-B)+C grown plants, but in other respects "deep mixed" sub-treatment affects on plant analyses differed. Plants grown on "deep mixed" soils differed widely in their Na and N percents with changes in treatment moisture. No yield difference resulted, however. As mentioned in an earlier section it is possible that the Stress treatment was not truly stressed enough to differentiate yields. If this was the case, a significant yield depression would not be achieved and such is the case. Generally, high moisture (1/10 Bar) decreased Mg % over low moisture (Stress), decreased % Na and % N in "deep mix" grown plants, and decreased % P in check and (A-B) grown plants. (Since yields did not significantly differ, changes in % may also be considered as changes in amount taken up).

The effect of added fertilizer on the crop response of individual sub-treatments is seen in Table 17. For plants grown on the check sub-treatment, fertilizer significantly increased yield, also significantly increasing plant N, and K with a less significant increase in P and Ca. (A-B)+C grown plants, though significantly increased in N, P and K and Ca through fertilization, achieved a significant yield increase at the 5% level only. Plants grown on the A+(B-C) sub-treatment responded

similarly in chemical change to fertilization as check and (A-B)+C sub-treatments though no Ca change was evident. A significant yield increase resulted. Plants grown on (A-B-C)+C sub-treatments responded similarly in chemical status to others grown under fertilization. However, these plants displayed a marked increase in Na% and a less significant Mg decrease while increasing in yield.

Generally then, all sub-treatments showed an N, P and K composition response to fertilizer. Check and (A-B)+C sub-treatments also showed a Ca response. The (A-B-C)+C sub-treatment gave a significant Na increase and less significant Mg decrease.

III. CONCLUSIONS

1. Yield - simulated deep plowing increased yields over the check under Stress and 1/10 Bar conditions. Mixing only A and B horizons decreased yield.
   - once fertilized, though previously mixed A, B and C horizons did not give a yield response, but under fertilization retaining the A horizon over a B-C mix increased yields significantly over the check. Under fertilization, mixing only A and B horizons decreased yield.
2. Mixing horizons - caused considerable chemical change in areas previously occupied by a single horizon - especially in pH, E.C., and Ca:Na ratios.
3. Cropping - altered the chemical status of all surface soils except the (A-B-C) mix.
4. Fertilizing - altered the chemical status of all surface soils when cropped, except the (A-B-C) mix.

5. Soil Mg - the surface soils that had the highest final Mg and Ca content were those that returned the highest yield.
6. E.C. and pH - high E.C. and low pH values did not reduce yield below the check.
7. Nitrate reduction - nitrogen was apparently lost in the A+B+C and (A-B)+C sub-treatments through anaerobic reduction. Such a loss does not seem to have occurred in A+(B-C)+C or (A-B-C)+C sub-treatments.
8. Perched water table - a perched water table was evident in A+B+C and (A-B)+C sub-treatments.
9. Added Fertilizer - caused consistent plant analyses changes in N, P and K only. Plant analysis changes in % Ca in A+B+C and (A-B)+C sub-treatments and changes in % N in (A-B-C)+C and A+(B-C)+C sub-treatments occurred in addition.

SUMMARY

Previous research involving the deep plowing of solonetzic soils has shown deep plowing to provide yield, fertility, infiltration and soil chemistry responses. The evaluation of a 7 year deep plowing field trial and a 6 week greenhouse experiment, both conducted on a Duagh Solonetz, has provided data which support these previous findings, as well as further isolating contributing factors.

The major benefit obtained from deep plowing a Duagh Solonetz appears to be that of decreasing inherent anaerobic potential within the check soil. It is postulated that a perched water table within the check soil has created anaerobic conditions which resulted in a fertility loss due to nitrate reduction. Deep plowing, due to its effect on the Ca:Na ratio of the soil, has caused increased soil aeration and prevented anaerobic conditions from occurring. Deep plowing, then, has not given a fertility response in the true sense but has simply prevented an anaerobic nitrogen loss from occurring.

In the majority of cases, fertilization alone (NPK) provided a greater response than did deep plowing alone. This appears to negate the need for deep plowing. However, fertility responses from field data have varied widely with individual years, and deep plowed soils have exhibited residual fertilizer effects which demonstrate a more efficient use of native and/or added fertilizer. Greenhouse observations have indicated the insufficiency of a single nitrogen application when check soils are subjected to high soil moisture conditions.

The majority of deep plowing experiments in the past have involved the complete mixture of A, B and C horizons. Greenhouse work on the

Duagh has indicated that even under fertilized conditions a significant yield benefit may be achieved from mixing only Band C horizons while retaining the A horizon on the surface. In no case did mixing only A and B horizons provide a yield increase.

Soil chemistry values other than N, P, and K concentrations and Ca:Na ratios appear to have little effect on productivity. Both low pH and very high E.C. values were tolerated in achieving maximum yields. There is some indication that soil Mg content may be related to yields.

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